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WITH 115 ILLUSTRATIONS.

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PREFACE.

THIS little book has been written principally to supply the want of a cheap and yet reliable text-book, experienced by the numerous Science Classes which have sprung into existence since Government has aided and encouraged the scientific education of the people. The plan of the book is original, but covers the syllabus drawn up by Professor Ramsay.

To prevent misconception, I will say at once that this book has no pretensions to be a guide to any examination, but is intended to introduce the really earnest student to the study of Geology. Examinations, however, are not to be ignored; it is indisputable that they are important and indispensable aids to education; but in my experience I find that a student who makes them the ultimatum of his study not only loses the true pleasure derived from an acquaintance with the secrets of nature and the accumulation of intellectual wealth, but he often acquires a secret distaste for the subject of his studies.

The student is, therefore, earnestly recommended to study this little work on Geology in the true spirit of a philosopher; let him study Geology as a geologist; let him endeavour to see and handle as far as possible all that which is merely described here, while at the same time he makes himself master of the theoretical explanations, and submits himself to occasional exercises and tests—let him do this, and while he enjoys the intellectual satisfaction which the study of nature always gives, he will in the surest manner be preparing himself for any examination at which he may wish to present himself.

W. S. D.

DERBY, *August* 1872.

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FIRST BOOK OF GEOLOGY.

CHAPTER I.

OBJECTS OF GEOLOGY—GENERAL STRUCTURE OF THE EARTH—ROCKS AND MINERALS.

1. **Objects of Geology.**[1]—The objects of Geology are very wide. The science aims at a complete investigation of the structure of the earth, and attempts to explain how the different varieties of structure have been brought about.

The size, shape, and density of the earth, and other questions with regard to its general structure, are particulars which concern Astronomy as well as Geology, and are principally supplied by the former science. The present condition of the earth's surface, with its distribution of land and water, irregularities of land surface, atmospheric phenomena, vegetable and animal life, together with many other similar topics, are matters which, although they are of great importance to Geology, are specially studied as a distinct science with the title of Physiography or Physical Geography. This leaves Geology to grapple, not so much with the earth as a whole or with what clothes its surface, as with the constitution of the surface itself and what is beneath it.

The earliest researches of Geology brought to light the important fact that the rocks composing the exterior of the earth are of different ages; each age of the world being represented by its own series of rocks. But what lends such interest and importance to Geology is, that the history of the past ages of the world is imprinted on the rocks themselves. These imprints consist principally of the remains of animals and plants which lived on the earth while the rocks were forming, and were enclosed in them, and, becoming converted into stone, were permanently preserved. These remains, which are well known as *fossils*, bear evidence of the condition of the earth's surface at the time when the rock which encloses them was formed; they tell of land and water, sunlight and air, and many other conditions necessary for animal and vegetable life; they help to furnish, in fact, an account of the Physical Geography of the age.

---

[1] Gr. *ge*, the earth; *logos*, an account of.

It will be seen that, as further acquaintance is made with the science of Geology, it concerns itself largely with the past history of the earth, and this history is read chiefly by means of the fossils enclosed in the rocks which form its exterior. These records are, however, unintelligible, except by the aid derived from close observation of the present state of things on the earth's surface.

2. General Structure of the Earth.—We learn from Astronomy that the earth is a globe with a mean diameter of 7912·4 miles. Its shape is not truly spherical, for it is somewhat flattened at two opposite points which coincide with its poles, or terminations of its axis of revolution. The *polar* diameter is 26½ miles less than the *equatorial* diameter.

The density or specific gravity of the earth as a whole has been ascertained to be about 5 or 6. That is, the earth would weigh five or six times as much as an equal-sized globe of water. The rocks occurring at the surface have only a specific gravity of 2½ or 3, which leads to the conclusion that the interior of the earth consists of denser, or heavier materials than those which are found at the surface. Whether the density of the earth goes on increasing to the centre or not, is a question to which no positive answer can yet be given.

The exterior of the earth consists of a solid structure with an irregular surface, presenting a successive variety of mountains, plains, and valleys. The deepest depressions are filled with water, and these constitute the oceans. It will be easily understood that the relative amount of land and water depends on the capacity of the parts which are depressed and the total quantity of water. Were the surface of the earth everywhere a geographical plain, the water would entirely cover it to a uniform depth. Above both land and sea we have the atmosphere, an ocean of air, which extends upwards for many miles and completely envelops the earth.

3. Crust of the Earth.—In another chapter reasons will be given which lead geologists to think the earth was once in a state of fusion, and that having gradually cooled by the radiation of its heat (the exterior more than the interior), a solid superficial layer was at length formed, and which is spoken of as the "Crust of the Earth." We may, however, apart from any theory, conveniently speak of the crust of the earth as being the solid exterior to which our direct observations are confined.

4. Rocks and Minerals.—The crust of the earth is made up of a variety of solid materials to which the general term *rock* is given. Not only are stony and compact rocks like sandstone, limestone, or granite, included under this term, but soft and loose matter such as clay and sand. In short, all solid matter not immediately derived from animal or vegetable sources, but which occurs naturally in large masses, is called rock by geologists.

Some rocks, such as limestones, have the same composition throughout. Others, when carefully examined, are seen to be made up of a mixture of crystals or small particles of different kinds. The distinct substances composing rocks are called *minerals*. In granite three different minerals can be easily made out. These are *quartz*, *felspar*, and *mica*. The crystals of felspar are most conspicuous; they are opaque and have flat faces. The mica occurs as thin scales, which readily cleave with the point of a knife into still thinner laminæ.[1] The quartz crystals are glassy-looking and more transparent than the felspar.

The number of distinct minerals occurring in nature is very large, and their study is embraced by the science of Mineralogy. The *rock-forming* minerals are, however, comparatively few; quartz, felspar, and mica are among these, and others will be described as occasion requires.

CHAPTER II.

STRATIFIED ROCKS—AQUEOUS ORIGIN OF STRATIFIED ROCKS—DESCRIPTION OF THE MORE COMMON AQUEOUS ROCKS—METAMORPHIC ROCKS.

5. Stratified Rocks.—The great majority of rocks appearing at the surface of the earth occur in regular beds, each bed preserving an almost uniform thickness over greater or less areas. Rocks of this class are called stratified.[2] They may be observed in almost every railway cutting, stone quarry, and sea-cliff; in mine shafts, foundations of buildings, and many other places where the surface or deeper rocks have been exposed.

It will be found, on inspecting the rocks themselves, that the strata are sometimes horizontal and sometimes inclined. Occasionally they are curved and crumpled.

The student should collect specimens of all the stratified rocks in his district, and closely study them.

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[1] Lat. *lamina*, a thin plate; pl. *laminæ*.

[2] Lat. *stratum*, spread or strewn out; pl. *strata*.

Additional characters belonging to this class of rocks may then be observed. In the first place, careful examination will generally show that they are either dull and earthy-looking—sometimes consisting of finely-powdered matter, such as clay, or of fine-grained stone like shale—or they will consist of rounded particles or fragments, which may be loose, as sand and pebbles, or consolidated, as sandstone and conglomerate. Again, the majority of stratified rocks are fossiliferous—that is to say, they contain remains of animals and plants converted into stone. There are few neighbourhoods where fossils do not occur, and the search for them is not one of the least engaging parts of geological study.

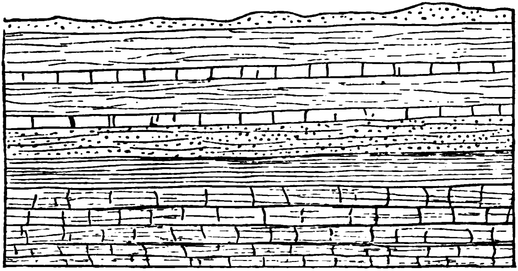

Fig. 1.—Stratified rocks as seen in railway cuttings, stone quarries, sea-cliffs, etc.

6. Aqueous Origin of Stratified Rocks.—The surface rocks of the land are continually being worn away by the action of rain, frost, running water, and other natural agents. The wasted material is carried away by streams and rivers into lakes or the sea, where it collects at the bottom, forming layers or beds.

Sea-breakers act destructively on the coasts, tearing away particles and fragments, and rolling them outwards into deeper water, where they accumulate, and form beds similar to those formed by the material brought down by rivers.

The mineral matter composing these beds consists of finely-ground particles in the form of mud or clay, or of grains of sand or pebbles.

Animals living in the sea or lakes, when they die, fall to the bottom, and their remains become buried in the sediments which are forming. In some parts of the ocean, far away from the land, the only accumulations at the bottom consist of the hard parts of marine animals large and small. This also applies to the neighbourhood of coral reefs, where there is nothing but animal structures for the breakers to destroy.

From what has already been stated of the characters of stratified rocks, we naturally come to the conclusion that they were formed by the various natural processes just enumerated. And, although these rocks now form dry land, and are occasionally inclined at all possible angles, and bent into all manner of curves, the conviction forces itself upon us, that wherever these rocks occur, there the sea, or possibly a lake, must have existed, and that the rocks themselves are nothing more than the accumulations of waste material at the bottom of such sea or lake.

It will be observed what an important part water plays in the production of stratified rocks; water to waste and destroy; water to transport; and water to spread out and accumulate. Hence, the term *aqueous*,[1] which is frequently applied to stratified rocks, is very expressive.

A more detailed account of the formation of aqueous rocks will be given in another chapter.

7. Summary of the Characters of Aqueous Rocks.—Aqueous rocks may be known by the following characters:—

1. By their being arranged in regular beds or strata.

2. By their consisting of finely-powdered matter, such as mud or clay; or of waterworn particles or fragments, such as sand or pebbles.

3. By their often containing the remains of animals

---

[1] Lat. *aqua*, water.

or plants, called fossils; or by their consisting almost entirely of such remains.

8. Description of the more common Aqueous Rocks.—A description of the more common aqueous rocks will now be given. Their characters must be studied from actual specimens.

The majority of aqueous rocks may be conveniently grouped under five heads according as they are of a fragmentary, sandy, clayey, limy, or carbonaceous nature. There are a few which will not come under either of these heads, as ironstone, rock-salt, etc.

1. FRAGMENTARY ROCKS.

9. Gravel.—Accumulations of small fragments, mostly waterworn and mixed with sand.

10. Shingle or Pebbles.—Hard waterworn fragments. The smoothness is due to their having had their sharp edges and angles worn off, by being rolled over and over in some stream or river, or by the advancing and retreating waves on a sea-beach. The process of pebble rounding may be watched, either in shallow brooks, or on a shingly beach.

11. Conglomerate.[1]—Also called puddingstone. A rock consisting of pebbles cemented together, the cementing material filling the interstices and rendering the whole compact.

The manner in which strata of loose fragments or particles become consolidated into hard rock will be described in another chapter.

12. Breccia.[2]—A rock consisting of angular fragments consolidated into hard stone.

2. ARENACEOUS[3] ROCKS.

13. Sand.—A good magnifying-glass shows sand to consist of minute rounded particles, miniature pebbles in fact. Grains of sand are rounded in a similar way to that in which pebbles are formed, that is, by the rubbing of the grains one against another as they are moved onwards in brooks, or pushed backwards and forwards by the waves on a sea-beach. Grains of sand consist almost entirely of the mineral quartz, which is one of the hardest of the rock-forming minerals. It is only moderately-hard particles which can form sand; softer particles are quickly ground into mud.

---

[1] Lat. *glomerare*, to gather into heaps.

[2] Italian, a crumb or fragment.

[3] Lat. *arena*, sand.

14. **Sandstone** is simply sand cemented together, or otherwise consolidated into hard stone. The waterworn grains may frequently be seen by examination with a magnifying-glass, especially if a weathered surface is examined. Sandstones often show a tendency to split up into slabs parallel to the stratification. Rocks which split up in this way are called *flagstones*, and are frequently used for paving-stones and other purposes.

15. **Gritstone.**—This term is restricted to varieties of sandstone in which the grains are large and somewhat angular. The more compact and durable kinds are used for millstones, grindstones, etc.

3. ARGILLACEOUS[1] ROCKS.

16. **Mud** is finely-powdered mineral matter, generally mixed with particles derived from vegetable and animal sources. It is the result of the waste of rocks by running water and other natural agents. Mud is the ultimate product of the action of these agents on the softer rocks, and of their prolonged action on the harder ones. The particles being small, are carried in suspension by running water, and deposited in spots where the water is quieter, as at the mouths of rivers. In this way accumulations of mud are formed, often unmixed with grosser particles.

17. **Clay** resembles mud in the fineness of its particles, but the particles adhere together, forming a tough material easily moulded by the fingers. Clay consists

---

[1] Lat. *argilla*, clay.

essentially of a substance, the chemical name of which is silicate of alumina. It may occur in a state of purity or be variously mixed with other substances. One important fact about clay is, that it is impervious to water. If we have in any district a series of porous strata, such as sand or gravel beds, lying upon a bed of clay, the rain which soaks into the ground will sink through the looser strata until it reaches the clay, and not being able to penetrate deeper will accumulate amongst the gravels.

18. **Shale** is hardened mud or clay which splits up into thin plates or laminæ parallel to the stratification. Such a rock is said to be laminated.

19. **Clay Slate.**—Ordinary roofing slate is an example of this rock. It consists of clay which has been hardened and otherwise changed. It has a distinct cleavage, generally so perfect that it readily splits into thin plates.

The cleavage is independent of the stratification. It is rarely parallel to the bedding, generally crossing the strata at all angles. If a piece of slate be examined, it will be found possible to continue the division until very thin scales are obtained. This peculiar structure is known as *slaty cleavage*. It will be more fully considered in another chapter.

20. **Loam** is a soft mixture of sand and clay. The presence of the sand renders it permeable to water.

4. CALCAREOUS[1] ROCKS.

21. This group includes limestones, chalk, and other rocks consisting wholly or mainly of carbonate of lime. When the purer kinds are burnt in a kiln, a gas called carbonic anhydride[2] is given off, and quicklime remains. Carbonic anhydride is also evolved when a fragment of limestone or rock containing even a small amount of calcareous matter is treated with an acid. The escape of gas gives rise to effervescence. Small fragments of the various calcareous rocks should be obtained and treated

---

[1] Lat. *calx*, *calcis*, lime.

[2] Commonly called carbonic acid.

with hydrochloric acid. All local specimens which are at all doubtful should be put to this test. Pure carbonate of lime is wholly dissolved by hydrochloric acid.

22. **Limestones.**—These are consolidated rocks, of which there are many varieties. Fossils are usually abundant in them; and some are visibly made up of fossil shells and other hard parts of animals. Limestones frequently form good building stones. Portland and Bath stone are well-known examples.

23. **Chalk** is a soft and very pure variety of limestone.

24. **Oolite**[1] **or Roe Stone** is a limestone made up of small round grains, which gives it a structure resembling the roe of a fish. *Pisolite* or *peagrit* has a similar structure to oolite, but the grains are flat and as large as peas.

25. **Magnesian Limestone** is a rock consisting of carbonate of magnesia, as well as carbonate of lime.

26. **Dolomite**[2] is a variety of magnesian limestone more or less crystalline. The crystals are small and compact. Dolomite often forms a good and durable building stone. It was selected by a Royal Commission as the material for the erection of the present Houses of Parliament. The expectations of the Commissioners with regard to its durability have, however, scarcely been realised. The Piccadilly front of the Royal School of Mines is also constructed of dolomite. In this case the material was carefully selected, and stands well.

27. **Marl** is calcareous clay. It breaks up into small square-like masses when dry.

28. **Gypsum** may be included in this group, seeing that it contains lime. It does not, however, effervesce with an acid, for it consists of sulphate and not carbonate of lime. *Alabaster* is a finely crystalline variety of gypsum.

5. CARBONACEOUS ROCKS.

29. **Coal** is a rock consisting almost entirely of carbon.

---

[1] Gr. *oon*, egg; *lithos*, stone.

[2] From *Dolomieu*, a distinguished mineralogist.

It is vegetable matter which has undergone considerable physical and chemical changes. The facts which lead to this conclusion will be given when the *origin* of coal comes to be considered. The numerous varieties of coal may be grouped under the heads of Lignite, Bituminous Coal, and Anthracite.

30. Lignite, or Brown Coal, is a carbonaceous rock, generally of a dark colour, sometimes quite black. It is usually softer and more brittle than ordinary coal, and frequently the structure of the plants from which it was derived is plainly seen.

31. Bituminous, or Common House Coal.—The colour, lustre, fracture, and other characters of this rock are well known. There are many varieties, the principal of which are:—1. *Caking Coal*, which becomes pasty when burnt, so that the particles cake or stick together. 2. *Splint or Hard Coal*, which is difficult to break, and does not easily take fire; it is, however, a useful variety, especially as a steam or furnace coal. 3. *Cherry or Soft Coal*, a free burning coal which leaves but little ash. It has a resinous lustre and shaly fracture, and is easily broken and ignited. 4. *Cannel Coal* varies much in appearance. It does not soil the fingers like other coals. It burns with a bright clear flame like a candle, and is a valuable coal for gas-making.

32. Anthracite is more compact and dense than ordinary coal. It has generally a shining and sometimes semi-metallic lustre, and does not soil the fingers. Anthracite burns without smoke or flame, and gives out an intense heat. About 90 per cent. of this rock is carbon, and 3 per cent. hydrogen, the remaining 7 per cent. consisting of oxygen, nitrogen, and earthy substances. Ordinary coal contains less carbon and more hydrogen than anthracite.

---

33. Metamorphic Rocks.—Stratified rocks occur here and there which have undergone change of structure since they were deposited. Their stratified character leaves no doubt of their sedimentary origin, but frequently all other traces of aqueous agency are obliterated, and they become more or less crystalline. Rocks of this nature are called *metamorphic.*[1] The most important are :—

34. Quartz Rock, or Quartzite.—A compact and granular rock, consisting of nearly pure quartz. The grains are distinctly rounded, but are agglutinated together as if by partial fusion. The evidence appears conclusive that the rock is an altered sandstone.

35. Mica Schist.[2]—A rock consisting of alternate laminæ of mica and quartz. The original texture of the rock is quite obliterated. It readily splits into thin laminæ or scales of *different mineral matter.* Such mode of division is called *foliation,*[3] and rocks which so divide are called *foliated* or *schistose.*

36. Gneiss consists of the same minerals of which granite is composed, viz. quartz, felspar, and mica. The crystals are not, however, confusedly mixed as they are in granite, but lie more or less parallel to each other, giving the rock a somewhat laminated or schistose structure.

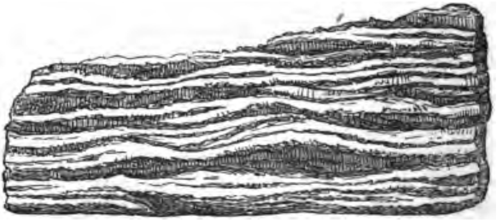

Fig. 2.—Fragment of gneiss, natural size; section made at right angles to the planes of foliation.

Gneiss varies very much in appearance. Sometimes the laminæ are very distinct, and preserve their parallelism for great distances. In other cases the laminæ are bent and folded, many folds occurring in the space of a few inches. Occasionally all traces of lamination are absent, and a hand specimen cannot be distinguished from granite. In this case the rock can only be identified by observing it *in situ*.[1] Even then it is sometimes difficult to decide whether it should be regarded as gneiss, or considered to be granite; there being every gradation between the typical kinds of the two rocks.

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[1] Gr. *meta,* change; *morphe,* form.

[2] Gr *schisma,* a splitting.

[3] Lat. *folium,* a leaf.

37. Granite has already been described, and will be referred to again in another place. Recent observations seem to show that many granites are highly metamorphosed sedimentary rocks, which have, in fact, passed a stage beyond the condition of gneiss, and have lost all traces of their original lamination and stratification.

38. Crystalline Limestone.—This rock, of which ordinary white marble is an example, has a finely crystalline structure, and takes a fine polish. It may be white, with a uniform texture, as statuary marble, or be variously coloured and veined, when it constitutes many of the marbles used for ornamental purposes.

39. Serpentine.—A compact amorphous[2] rock, consisting chiefly of silicate of magnesia. Its colour is generally green, and sometimes it is variegated so as to resemble the markings on the skin of a serpent. It generally occurs associated with altered limestone.

CHAPTER III.

IGNEOUS ROCKS.

40. Igneous Rocks.—All rocks which do not come under the definition of aqueous or metamorphic, show signs of having once been in a state of fusion, and for this reason they are called *igneous*[1] *rocks.* They have usually a crystalline structure, and generally occur in irregular masses, destitute of stratification.

---

[1] Lat. in its natural situation or place.

[2] Gr. *a*, without; *morphe*, form; destitute of crystalline structure.

41. Volcanic Rocks.—The lavas and ashes ejected by volcanoes are good examples of igneous rocks. These are distinguished as *volcanic rocks.* They present many appearances due to the fusion and subsequent cooling which they have undergone. Some are quite glassy in appearance, others have a wavy structure, like the slag which flows from iron furnaces, while many are full of cavities like a cinder. Pumice is an example of the latter. The vesicular[2] structure is caused by the presence of gases and watery vapour in the molten lava, and which, by their expanding and efforts to escape, blow out the pasty mass into bubbles, forming numerous small cavities or vesicles. A similar structure is seen in bread, the spongy texture being due to the generation of carbonic anhydride by the fermenting action of the yeast. Stratified rocks never have a vesicular structure.

Lavas are frequently crystalline in structure; the crystals having formed as the rock slowly cooled.

42. Other Igneous Rocks.—Besides the products of modern volcanoes, other rocks are abundant in some districts, which show unmistakable signs of having once been in a state of fusion. Such rocks are plentiful in Scotland, Cumberland, Wales, and other parts of Great Britain. Many of these were ancient lava streams and beds of ashes, formerly covered up and preserved, but since exposed. Others were masses of fused rock, forced up from below, but which never reached the surface. Basalt, greenstone, and granite are examples. These, and many others of similar origin, are grouped along with volcanic products under the head of igneous rocks.

43. Interstratified Lavas and Ashes.—Ancient lavas often occur interstratified with aqueous rocks—that is to say, we often find a stratum of what was once molten lava with true aqueous strata above and below it. If we examine the strata in actual contact with the igneous rock above and below, we find in all cases that the stratum upon which it rests has been altered as if by intense heat, while the stratum which covers it is in some cases similarly changed, but in others quite unaltered.

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[1] Lat. *ignis*, fire.

[2] Lat. *vesicula*, a little bladder.

When the stratum above the igneous rock is unaltered, we infer that the lava was the product of a submarine volcano; the lava being poured out over the bottom of the sea, and afterwards, when cool, buried by subsequent deposits. A lava bed of this kind is said to be *contemporaneous*—that is to say, its age is represented by the interval between the strata below and above it. A good example of ancient contemporaneous lava is the "toadstone" associated with the limestone strata of Derbyshire.

Beds of volcanic ashes are not unfrequently found interbedded with aqueous rocks. They must have accumulated at the bottom of the sea, being derived either from submarine volcanoes, or from volcanoes on neighbouring coasts. Aqueous strata being afterwards deposited upon these beds, they become interstratified as we find them.

44. Intrusive Igneous Rocks.—Igneous rocks commonly cut more or less vertically through sedimentary strata, as if they had originated deep in the earth, and had been forced upwards in a liquid state, filling, and consolidating in, any spaces, such as fractures, which may

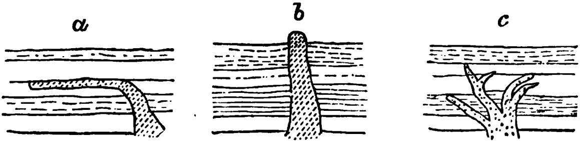

Fig. 3.—Intrusive igneous rocks.

a Interstratified. *b* Dyke. *c* Veins.

exist. They are then said to be intrusive. The more vertical sheets, when exposed to view, are often wall-like in appearance, and are called *dykes*.[1] Igneous rocks often form branching veins, penetrating strata in all directions.

When it happens, in the case of an interstratified igneous rock, that the strata both below and *above* it are altered, then the igneous rock must have been forced in a molten state between the two strata; or, in other words, the lava is intrusive, and not contemporaneous.

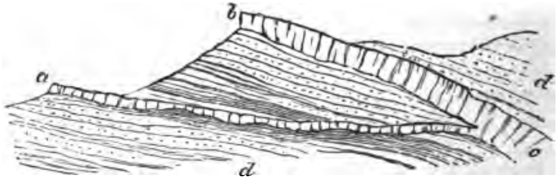

Fig. 4.—Intrusive sheets of dolerite, Edinburgh.

a Dolerite. *b* Strata of sandstones and shales.

45. Two Kinds of Intrusive Rocks.—Intrusive igneous rocks are of two kinds—*volcanic* and *granitic*. The former resemble in composition and structure the lavas of recent volcanoes; but having consolidated without reaching the surface, they are usually denser and more compact in structure than modern lavas. They are frequently termed *trap*[2] *rocks* to distinguish them from recent volcanic products. Granitic rocks are such as resemble granite. They are completely crystalline, and seem to have consolidated very slowly, and under great pressure. They are never vesicular, nor are they ever associated with ashes and fragments, such as accompany lavas.

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[1] Scot. a wall or fence.

[2] Swed. *trappa*, a stair, from the step-like appearance which these rocks frequently give to the hills where they occur.

The occurrence of intrusive rocks is generally associated with a disturbed condition of the adjacent strata; that is, the beds are bent, folded, broken, or otherwise thrown out of their original position. Also, where contact takes place between aqueous and igneous rocks, the former seem to have undergone considerable change; they have become baked, as it were, and in some cases have suffered partial fusion, thereby becoming hard and crystalline. They have been, to use the technical term, metamorphosed.

46. Summary of the Characters of Igneous Rocks.—Igneous rocks may be known by the following characters:—

1. By their occurring in irregular masses, penetrating stratified rocks as dykes, veins, etc.
2. By their often having a glassy and wavy structure, like slags from metal furnaces. Many lavas have this structure.
3. By their often being full of cavities (vesicular), as in the case of pumice.
4. By their having crystals scattered through them, or by their being completely crystalline.

47. Description of the more Common Igneous Rocks.—It will now be necessary for the student to study the characters of the more important igneous rocks. The descriptions which are here given must be carefully followed with specimens at hand.

1. VOLCANIC ROCKS.

48. Volcanic Ashes.—The boiling up of molten lava in the crater of a volcano gives rise to large quantities of dust and fragments, which are called volcanic ashes, scoriæ, or tuff. The ashes consist principally of the broken films of innumerable bubbles, which are formed by the rapid escape of gas from the liquid lava. The ashes are carried upwards by the current of vapours and gases, and at length fall around the crater. The lighter portions may be carried many miles by the wind. Volcanic mountains consist mainly of accumulations of fragments and ashes, which have been ejected by the volcanoes themselves, bound together and strengthened by consolidated lava streams.

Volcanic ashes may remain in a loose, pulverulent condition, or become consolidated into stone, either by mere pressure of further accumulations, or by being mixed with water, which converts the ashes into mud; and this often sets, on drying, like mortar or cement. In the excavations made at Pompeii and Herculaneum, a soft kind of stone has to be cut through, consisting of the consolidated ashes which overwhelmed these unfortunate cities. The volcanic ash which fell upon Herculaneum was mixed with water, which has rendered it much harder than that which is met with at Pompeii.

49. **Trachyte** is a lava consisting principally of the mineral felspar. It is usually light coloured, and feels rough and prickly to the finger. There are many varieties. Trachyte is generally abundant in volcanic districts, but is one of the rarest of British rocks.

50. **Obsidian, or Volcanic Glass,** is a variety of trachyte, which has the appearance of coarse bottle-glass. It is, in fact, a natural glass, having a similar composition to that produced in a glass furnace.

51. **Pumice** is a light and porous variety of trachyte. It is really the froth of lava. The origin of the vesicular structure which pumice has, in common with some other lavas, has already been described (41).

52. **Dolerite.**—A lava consisting of felspar, together with a large proportion of the mineral called augite. This mineral has a black or greenish-black colour, and occurs in dolerite either as distinct crystals, or as angular and roundish grains. Dolerite is always heavier, and generally of a darker colour, than trachyte.

53. **Basalt** is a hard, compact, and dark-coloured

rock, with a conchoidal[1] fracture. It is similar in composition to dolerite, but differs from it in being amorphous.

Basalt often occurs in columns, more or less hexagonal in section. The columnar structure of the basaltic rocks of the Giant's Causeway and Fingal's Cave are well known.

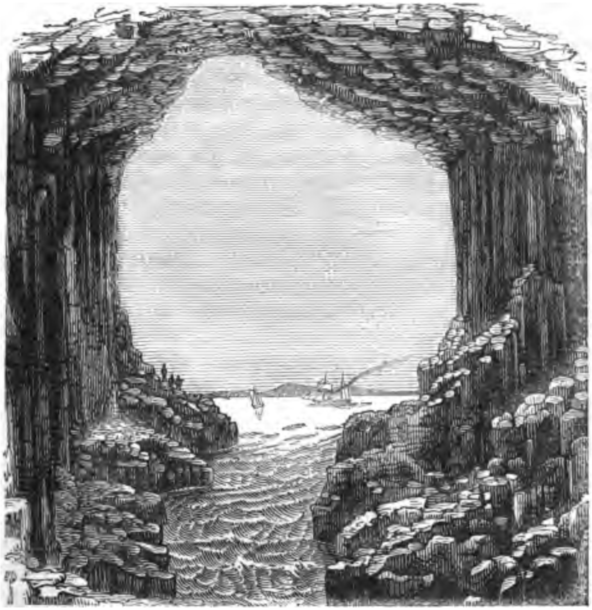

Fig. 5.—Fingal's Cave.

This columnar structure is assumed by the lava in passing slowly from the liquid to the solid state. Starch assumes a similar form on drying. If the flakes of starch, as usually sold, are examined, they will be found to be rudely hexagonal in shape.

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[1] Gr. *konche*, shell; *eidos*, form; with concave and convex surfaces, like shells.

54. **Greenstone, or Diorite,** is a compact rock, like basalt, but is distinctly crystalline. The prevailing mineral is *hornblende,* which resembles augite in colour and composition. The rest of the rock is made up of felspar, which is easily distinguished from the hornblende.

2. GRANITIC ROCKS.

55. **Granite** frequently occurs as a true igneous rock, penetrating strata, and sending branching veins in all directions. Its mineral constitution has already been described (4.) Granite is easily distinguished from other rocks by its mottled appearance, and the ease with which its different crystals can be recognised. The crystals of felspar are sometimes large and conspicuous, when the rock is called *porphyritic*[1] *granite.* Much of the Dartmoor granite is of this character.

The word *porphyry* (originally applied to an igneous rock of deep red colour) is employed to denote any rock which contains conspicuous crystals differing from the mineral matter in which they are embedded.

Granite and granitic rocks occur abundantly in some parts of the British islands. They constitute the larger portion of the Grampians in Scotland, and the mountains of Cumberland, Devon, and Cornwall. They occur in the Wicklow mountains in Ireland, and show themselves in smaller bosses and veins in several other places.

56. **Syenite**[2] is a kind of granite, consisting essentially of the minerals quartz, felspar, and hornblende. The felspar is generally red, and the hornblende of a dark-green colour.

57. **Summary.**—In the three preceding chapters, a general account has been given of the structure of the earth,

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[1] Gr. *porphyreos,* purple.

[2] From *Syene,* a city in Upper Egypt, where this rock occurs.

and the nature and constitution of the rocks which form its crust. These rocks, we have seen, may be grouped into two great classes—aqueous and igneous—according as their origin chiefly resulted from the agency of water or heat. Sandstone, limestone, and shale are good examples of aqueous rocks; and basalt, greenstone, and pumice, of igneous rocks. Metamorphic rocks form a subclass of aqueous rocks; gneiss and crystalline limestone are examples.

We shall now devote a few chapters to a detailed account of the agencies concerned in the formation of aqueous rocks.

CHAPTER IV.

CLASSIFICATION OF AQUEOUS ROCKS ACCORDING TO MODE OF ORIGIN—DISINTEGRATING AGENTS—CHEMICAL DISINTEGRATION.

58. **Aqueous Rocks** may be grouped into three classes according to their mode of origin, viz.—(1.) *Mechanically formed rocks*, those formed by purely mechanical means from the ruins of previously existing rocks, such as conglomerate, sand, sandstone, clay, and shale; (2.) *Organically formed rocks*, those consisting of accumulations of vegetable or animal remains, such as peat, coal, and many limestones; (3.) *Chemically formed rocks*, those produced by chemical means; gypsum, rock-salt, and some limestones belong to this class.

59. **Agents concerned in producing Aqueous Rocks.**—When a large building is in course of erection, the stone and other material with which it is constructed have usually to be obtained from a distance; thus employment is given to three classes of labourers—one to quarry and shape, another to convey to the required spot, and the

third to build. Three similar classes of agents operate in nature, in the formation of all sedimentary rocks. We have *agents of waste*, which, by their action on the land, loosen particles and fragments, and so shape them that they are easily carried away by moving water or air; *agents of transportation*, which remove these materials, and carry them to lakes or the sea; and, finally, we have the *agents of reconstruction*, concerned in the sifting, spreading out, and consolidating of the transported material.

60. Disintegrating Agents.—The natural agents by which the land is gradually worn away are called *disintegrating*[1] *agents*. They are also known as *erosive*[2] *agents*. Their operations on the land tend to lower its surface, little by little. They also, by stripping off the upper rocks, expose those beneath. Hence they are called *degrading*[3] or *denuding*[4] agents.

The land suffers waste both upon its surface and at its edge. The disintegrating agents acting on the surface are called *atmospheric;* those acting on the edge, *marine*.

The following is an enumeration of the principal agents of erosion:—

I. ATMOSPHERIC—(*a*) *Chemical.*—Water and carbonic acid; (*b*) *Mechanical.*—Snow, frost, glaciers, rain, running water in the various forms of springs, brooks, rivers, waterfalls, floods, &c.

II. MARINE—Sea-breakers, tides, marine currents.

CHEMICAL DISINTEGRATION.

61. Solvent Power of Water.—When rain falls on the land, part of it evaporates and returns to the clouds; another portion percolates through the soil, to reappear as springs; while a large portion, especially in hilly districts, flows over the surface, and at length unites with the supply from springs, giving rise to the innumerable brooks and rivers. Water, in flowing over the surface of rocks, or in percolating through them, dissolves whatever is soluble. Some rocks contain a considerable amount of soluble matter, and the water which flows from them is often highly charged with mineral matter. This is the origin of the various mineral springs.

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[1] Lat. *dis*, asunder; *integer*, whole.
[2] Lat. *erosus*, gnawed or worn away.
[3] Lat. *de*, down; *gradus*, a stage.
[4] Lat. *nudus*, naked.

Common salt, gypsum, and a few other constituents of rocks, are dissolved by water alone; but when water contains certain substances in solution, many constituents of rocks are acted on and dissolved which are altogether insoluble in pure water.

62. Carbonic Acid.—It has already been stated that this gas is liberated when a fragment of limestone is treated with an acid (21). It is always present in small quantities in the air, and is being continually generated in the soil by the decomposition of vegetable and animal matter. It is soluble to some extent in water, and rain water absorbs it in falling through the air and soaking through the soil. The consequence is, that all natural waters contain more or less of this gas in solution.

Carbonate of lime is insoluble in pure water; but when water contains carbonic acid in solution, the latter converts the carbonate of lime into bicarbonate, which is soluble. This chemical principle operates in nature on a large scale, and all exposed limestone rocks are being slowly dissolved by the rain water which flows over them. Water, entering the crevices and joints, dissolves away the sides and widens them. In many limestone districts, the continual widening of what were formerly mere joints has led to the formation of caverns, some of which ramify through the rocks to great distances, and in many cases streams still flow through them, and continue, though imperceptibly, to enlarge them.

The water of springs and streams is generally hard, particularly in limestone districts. The hardness may be due either to the presence of bicarbonate of lime, or to that of sulphate of lime. In the former case, the hardness is *temporary*, for on boiling the water, the excess of carbonic acid is driven off, and the lime is precipitated as carbonate. In the latter case, the hardness is *permanent*, because the sulphate of lime is not rendered insoluble by boiling the water.

The disintegrating action of carbonic acid is not confined to pure limestones. All rocks containing calcareous matter are attacked by it, and when, as it sometimes happens, a rock consists of particles cemented together by carbonate of lime, the solution of the cementing material liberates the particles, and the rock undergoes rapid waste.

Many of the crystalline rocks, and granite among them, are attacked by carbonic acid. In the case of granite, it is the felspar which is acted on. This substance consists of silicate of alumina and silicate of potash (or soda). Carbonic acid in the presence of water decomposes the silicate of potash, forming carbonate of potash, which is dissolved and carried away by the water. It is easy to understand that any one constituent of granite being thus decomposed, the other constituents will be freed, and will be readily removed by running water.

CHAPTER V.

MECHANICAL DISINTEGRATION—ICE—LANDSLIPS—RUNNING WATER.

63. **Frost.**—The expansion which water undergoes in becoming ice has a powerful effect in the disintegration of rocks. When water which has entered into the joints and between the particles of rocks becomes frozen in winter, the blocks and particles are forced apart. The displacement is not evident while the frost lasts, for the ice acts as a cement, binding the particles together; but when the thaw comes, the loosened pieces and particles

of rock fall asunder, and thus great waste is effected whenever frost occurs.

The disintegration of rocks due to the action of rain, carbonic acid, and frost, is often spoken of as the *weathering* of rocks.

64. **Snow** often gives rise to the destruction of rocks, although it acts protectively on the land as long as it remains stationary and unmelted. In mountainous districts, accumulations of snow, from one cause or other, are apt to get loosened, and slide down the mountain side, sweeping before them all loose and easily detached rocks. The fearful *avalanches* common in the Alps are familiar examples.

It sometimes happens that, when warm weather sets in rather suddenly, the snow accumulated on hilly ground is rapidly melted, and the brooks and rivers are supplied with more water than will fill their channels, thus giving rise to large and destructive floods.

65. **Glaciers** are extensive masses of ice which creep down the valleys of mountain ranges whose peaks rise above the limit of perpetual snow. In the Alps, the glaciers are often ten or twenty miles in length, and a mile in breadth. They occur on a much larger scale in the Himalayas, the mountains of New Zealand, and other places; while in polar regions, as in Greenland, the whole ground is covered with one vast sheet of ice sliding imperceptibly towards the sea.

Glaciers are part of the natural system of drainage, only they drain solid, instead of liquid water. They are rivers of ice, and are supplied by the snow which is ever collecting on the mountain tops. Glaciers originate in this way:—The snow which accumulates in the valleys near the snow-line is subject to an alternation of partial melting and refreezing, which converts it into a mass of small icy particles called *névé*. The deeper portions of the *névé*, from the pressure of the layers above, become converted into ice. This ice forms the glacier, which moves slowly down the mountain sides, occupying valleys which it has helped to form, and which it continues to scoop deeper. Sometimes two or more glaciers unite to form one trunk, just as the tributaries of a river unite to form the main stream.

66. Motion of Glaciers.—Glaciers descend partly on account of their own weight, and partly from the pressure of the mass of snow and ice resting upon them above. The rate of progress of a glacier depends on the inclination of its bed, and on its own mass. The rate is never very great. Some points on the *Mer de Glace*, a glacier of the Alps, have been observed to creep as much as 30 inches a day in summer; but generally, glaciers do not move faster than 10 or 12 inches a day, or a mile in about twenty years.

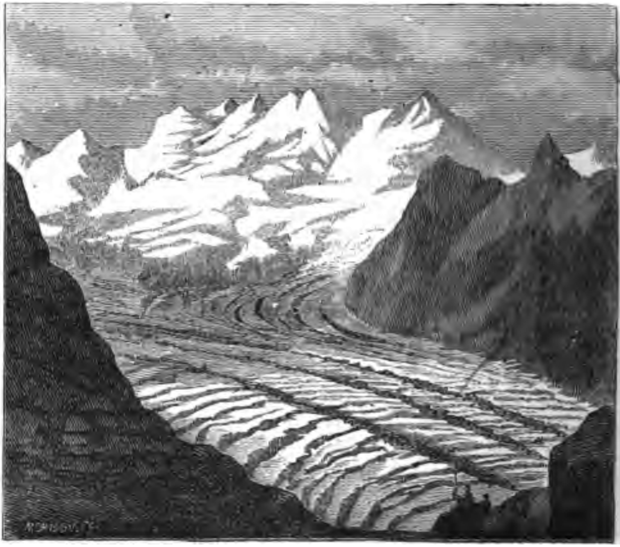

Fig. 6.—The Görner Glacier, Alps, with crevasses, moraines, and snowy heights in the distance.

The middle of a glacier moves faster than its sides, and the surface more quickly than the bottom; and where its course is curved, the line of most rapid movement is nearer the outside than the inside of the curve. In all these respects the motion of a glacier resembles that of a river. It also, like a stream of water, accommodates itself to the size of its bed, which varies in width and depth in various parts, behaving as if it were a viscid liquid. It does not, however, *flow* like a liquid. It can only alter its shape by undergoing innumerable fractures; but the separated surfaces, when pressed together, quickly reunite, and the ice becomes continuous again. This peculiar property of ice is called *regelation*;[1] it may be studied by experimenting with ordinary ice. If two pieces of ice are pressed together for a short time, they become frozen into one mass.

The irregular motion of glaciers gives rise to deep cracks and fissures called *crevasses*, which frequently extend from one side of the glacier to the other. Old crevasses are constantly closing up, while new ones form, and these, cutting the old ones across, cause the very uneven surface which glaciers usually have.

The surfaces of glaciers are always subject to thaw, especially in summer, when numerous streams of water flow over them, most of which are received into the crevasses, and find a channel underneath the ice. The lower portion of the glacier having descended into the warmer air, necessarily melts faster than the upper portion; and it gradually contracts in size, until it terminates, often with a precipitous front, at a point where the melting of the ice keeps pace with the advance of the glacier.

67. Transport of Matter by Glaciers.—The rocks above the origin of a glacier, and about its sides, are often steep and uncovered with snow; they are, therefore, subject to all the disintegrating influences of the atmosphere. Fragments of rock, large and small, become loosened from the exposed surfaces, and rolling down to the margins of the glacier, are carried down by it, forming long continuous lines of blocks and fragments along its sides.

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[1] Lat. *re*, again; *gelare*, to freeze.

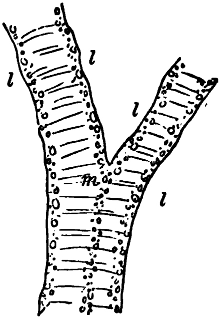

Fig. 7.—Diagram showing the formation of a medial moraine (*m*). *l* Lateral moraines.

The accumulations of rocky matter at the sides of glaciers are called *lateral moraines.* In cases where two glaciers unite, the union of the lateral moraines at the adjacent sides of the two glaciers gives rise to a mound of fragments extending down the middle of the main glacier, forming what is called a *medial moraine.*

At the termination of a glacier, all the larger moraine masses are brought to a standstill, the stream of water into which the glacier resolves itself being unable to continue the transportation of anything but the smallest fragments and mud. There is thus formed at the end of the glacier a confused heap of blocks and fragments of stone of all sizes and shapes. Such accumulations are called *terminal moraines.* They are still the prey of disintegrating agents, by which they are gradually eroded and carried away.

68. Erosion of Rocks over which Glaciers flow.—It is easy to conceive that the motion of a large mass of ice like that of a glacier must exert great erosive effect on the rocks over which it moves. Moving ice, unlike water, does not readily divide on meeting an obstacle, but tends to push it onwards. By this means all loose stones in the bed of the glacier are torn up, projecting edges and angles planed off, and the whole bed ground into a smooth undulating surface.

The small particles worn from the floor of the glacier, and also those which are carried into the crevasses by streams of water, being imprisoned between the ice and the rocky bed, act like so much emery powder, and the bed becomes not only smooth but polished. The general smoothness of the polished floor is, however, interfered with by the numerous angular fragments of rock which fall through the crevasses from the surface of the glacier. These being rubbed along, with all the weight of the ice above them, scratch and groove the bed in the direction in which they are moving; the stones themselves becoming scratched and furrowed by the same operation.

69. Signs left by Glaciers which have disappeared.—Many of the Swiss glaciers are known to have diminished in size within the memory of man, and some which once occupied valleys in the Alps, and elsewhere, have quite disappeared, and their original position can only be inferred from the marks they have left behind. These consist of wavy and polished beds, with longitudinal striations and furrows; also of moraine heaps, containing many scratched and furrowed stones. The rounded humps of rock occurring in the beds of ancient glaciers have a fanciful resemblance to the backs of a flock of sheep, and are called *roches moutonnées*.[1] These have often huge blocks of stone perched on the top, which have been left there as the glacier gradually declined in size. It is

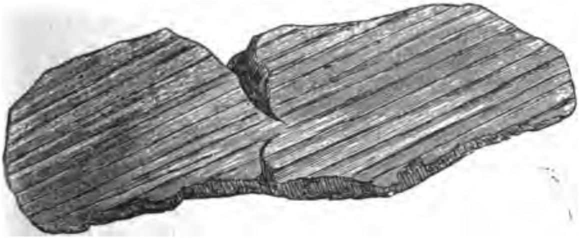

Fig. 8.—Fragment of rock striated by a glacier.

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[1] Fr. *roche*, a rock; *moutonné*, sheep-like.

interesting to know that many of the mountain valleys of our own islands present similar marks, giving evidence that these valleys were formerly occupied by glaciers.

70. Icebergs.—As we approach the polar regions, the snow-line descends lower and lower, and at length reaches the sea-level. In these regions, glaciers are only terminated by finding their way into the sea. If the coast is high and steep, the descending glaciers project over the edge of the cliffs, when the ice, being unsupported, breaks away in pieces and falls into the sea below. More frequently the glaciers descend to the sea down gentle slopes; and the ice, as it is pushed forward into the sea, being lighter than water, is buoyed up and tends to float. The consequence is, that large masses are broken off and float away as icebergs.

Icebergs, before they are completely melted, may be drifted by the winds and currents to great distances, even thousands of miles from where they were formed. Being parts of the original glacial ice, they carry with them masses of rock of all sizes, together with much finer detritus,[1] all of which, by the melting of the ice, is distributed over the sea-bottom, mingling with the deposits already forming there.

71. Landslips.—It often happens in hilly districts, and on the sea-shore, that large masses of strata, sometimes many acres in extent, slip bodily forward from higher to lower levels, carrying with them trees, fields, houses, or whatever may be upon the land. These are *landslips.* In nearly all cases they are brought about by the action of rain-water, which, soaking into the ground, and at length accumulating upon a bed of clay, or some such stratum, loosens the cohesion between it and the upper beds, when, if the strata are favourably placed, it may happen that the upper layers will slide over the slippery clay in the direction in which the strata are inclined, and thus become a landslip.

By means of landslips, masses of rock are brought into positions favourable for disintegration: rocks from hill sides are brought within the action of the streams of the valleys; and those from sea-cliffs are delivered over to the mercy of the waves.

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[1] Lat. *de*, down; *tritus*, rubbed or worn.

72. Running Water.—Rain-water which flows over the surface, sweeps before it particles of mineral matter which have been loosened by the action of the weather, thus scouring the rocks and leaving their surfaces clean for the renewed action of the agents of waste.

Running water impinging on obstacles tends to move them onwards; and when the velocity is great, as in mountain torrents, stones are loosened and dislodged from the beds and sides of the streams. These stones are sooner or later moved onwards, and rubbing along on the bottom of the stream, they assist to wear it deeper. The stones themselves are also worn, and soon become pebbles, by the rubbing down of projecting edges and angles: in like manner the smaller particles, if hard enough, become sand (*see* 10, 13). The attrition is continued in the brooks and small streams until the detritus is delivered to the rivers, principally in the form of fine sand or mud. As the bed of the stream deepens, the sides become more exposed, and these crumbling away, the debris[1] falls into the stream, and is by it carried away.

When it happens that a stream, after flowing over hard and compact strata, comes to a point where the rocks are much softer, it wears away the softer rocks faster than the harder ones, and a waterfall is produced. Waterfalls slowly cut their way back, by undermining the harder rock, which, becoming unsupported, breaks away from the edge over which the water flows. The Falls of Niagara have by their recession cut a ravine 7 miles long, 200 to 400 yards wide, and 200 to 300 feet deep.

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[1] Fr. wreck or waste.

CHAPTER VI.

GENERAL EFFECTS OF ATMOSPHERIC DENUDATION—MARINE DENUDATION.

73. Atmospheric, or Subaerial Denudation.—It will be convenient now to consider the work of the atmospheric agents of waste in another light—namely, in that of their influence on the form of ground. The general tendency of these agents is to lower the level of the land, but unequally; for rocks vary in composition and hardness, and some from their position are more liable to destruction than others.

74. Mountains and Hills consist of the harder rocks, or such as are favourably placed to resist denudation. Their summits in many cases are not more elevated than the original level of the surrounding district, the valleys having been formed by the removal of the matter which once filled them. In some hills and mountains, denudation has taken place all round them, while in other cases hills have been formed by the general lowering of a district on one side of an irregular line, leaving that on the other side at a greater elevation. On ascending such hills, we find ourselves on a new level, on a plateau, in fact, with no declivity on the other side, as we may have expected. Hills of this kind are numerous. The Cotswolds present a good example. The descent from the higher to the lower level is generally more or less preci-

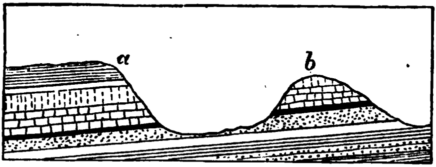

Fig. 9.—Diagram showing effects of denudation.
a Escarpment. *b* Outlier.

pitous, and is called an *escarpment*,[1] and there are often in the neighbourhood of the escarpment isolated hills which have escaped denudation. These are called *outliers*. The position and succession of the strata in the outlier corresponding with that of the escarpment, proves conclusively that the interval between the two was once filled by the strata being continuous across, and gives at once an idea of the vast amount of matter removed by denudation.

75. Denudation of Curved Strata.—Strata are often more or less curved or folded, just like the curves and folds that are produced in a pile of cloths when pushed together laterally. The curves with the convexity upwards are called *anticlinal*,[2] those with the convexity downwards, *synclinal*.[3] In districts where the strata are curved, we can readily trace the work of denudation. The section Fig. 10 will help to make this plain. A B is the present surface of the land. In passing from A to B, we should find different strata coming to the surface,—first of all 1, dipping to the east, then 2, and presently 3, dipping to the west. On examination, 3 proves to be identical with 1, and as they dip *towards* each other, it is pretty certain they are continuous underground

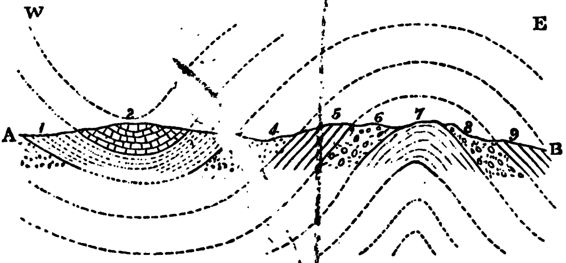

Fig. 10.

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[1] Fr. *escarper*, to cut steep.
[2] Gr. *anti*, on opposite sides; *clino*, I bend.
[3] Gr. *syn*, together

We now pass over 4, 5, 6, each of which dips below the preceding one, and all dip to the west. After passing over 7, we come to 8, identical with 6, 9 with 5, and 10 with 4. The corresponding beds in this case cannot be continuous underground, because they *dip away from each other*. The inference is plain; these beds were once continuous *above* the present surface of the land, the upper portions having been removed by extensive atmospheric or marine denudation, or both combined.

76. River Valleys.—Rivers, in the upper part of their course, and frequently for their whole length, flow through valleys. It is probable that in nearly all cases the valleys owe their origin to the streams which now flow, and have flowed, through them. Rivers, unless very sluggish, continue to deepen their beds. The rapidity with which they do so depends on the velocity of the stream, and on the nature of the rocks forming their beds.

The deeper a stream cuts its bed, the higher its banks tend to be; but, at the same time, they become more favourably placed for denudation. It sometimes happens that a river deepens its bed more rapidly than the rocks forming its sides are destroyed, when, instead of flowing through a valley, the river will flow through a ravine, with sides more or less precipitous. A good example of this is afforded by the river Colorado and its tributaries, which flow for hundreds of miles through deep gorges called *cañons.*

More generally, however, the disintegration of the banks of a river goes on at a rapid rate, the detritus finding its way into the river, by which it is removed. This tends to form a sloping declivity on each side of the river, down which the eroded material from higher levels is easily swept. In this way a river of moderate size may in time form a broad valley.. There are other causes which may help to widen a river valley, such as the frequent overflowing of the river, or the occasional changing of its course. Moreover, rivers have a peculiar tendency to wind about, a great many convolutions sometimes occurring in the space of a mile or two. The tortuous course of a river results from the operation of the natural law, that a mass of matter in motion tends to move in a straight line. The consequence is, that wherever there are any accidental curves in the course of a river, the current, tending to preserve a straight course, will be principally directed on the concave bank, and will continually cut this back, while deposits of gravel or other detritus will take place on the opposite side, where the motion is slower. The diagram Fig. 11 will assist in making this clear.

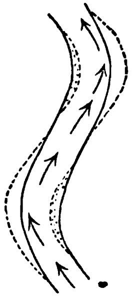

Fig. 11.

In many valleys, river gravels occur at various heights above the present level of the river, which show it to have formerly flowed at a higher level than at present. The gradual deepening of the valley, or decline in the size of the river, has in many cases given rise to step-like banks, or terraces on the sides of the valley. Good examples occur in the valley of the Thames.

77. Marine Denudation.—The sea-coasts are not only subject to the wasting influence of the ordinary atmospheric agents, but are rapidly eroded and destroyed by the movements of the sea, principally by the breakers, which are aided in their action by the tides. Sea-breakers are simply the wind-waves formed on the surface of the sea, and which, on reaching the shallower water near the shore, are thrown more or less forcibly forward. During storms the waves acquire great force, and break with violence on the rocky shores. No rock can permanently withstand the terrible battering of these breakers. Blocks of stone are loosened and dislodged from compact rocks; while the softer rocks, such as clay, sand, or gravel, are destroyed with surprising rapidity. The power of the breakers to roll about and remove huge blocks of stone is better understood when it is known that rock of average density has quite one-third of its weight counteracted by the buoyancy of the water. The loosened blocks are still subject to disintegration, and are broken in time into fragments, which soon become pebbles by being constantly rolled to and fro by the advancing and retreating waves. During storms, pebbles, sand, and fragments of all kinds are driven against the cliffs, thus helping on the work of destruction.

The rising and falling tide assists the action of the breakers by continually changing their level of action.

Destructive as the sea-breakers are at the base of the cliff, the atmospheric agents are usually still more active at the upper parts; in consequence of which, the majority of sea-cliffs slope backwards. Sometimes the faces of cliffs are vertical, showing that the atmospheric erosion keeps pace with that of the sea. When, as it occasionally happens, the sea eats away the base of the cliff faster than the part above the sea-level is wasted, the cliff overhangs the sea, the unsupported blocks now and again falling away.

Landslips are common on some coasts, and by their aid large masses of strata are brought within the immediate action of the sea.

78. **The Rate at which Sea-cliffs are cut back** depends on the nature of the rock, and position of the beds when stratified, as well as on the force of the breakers. Where the cliffs consist of beds of sand, gravel, clay, or other soft strata, as they do on some parts of the east coast of England, the sea advances at a very perceptible rate, amounting in many places to 2 or 3 feet per annum. The chalk cliffs in the east and south of England resist the action longer, but the progress of their destruction is still very evident. It is only where the rocks are compact and durable, such as the igneous and metamorphic rocks which form many of the promontories in our islands, that the encroachment of the sea is not

so obvious; but even with these, destruction is only a question of time.

79. General Effects of Marine Denudation.—The various agents of waste, whether subaerial or marine, continue to act on the land as long as any portion of it is above the sea-level. The mode of action of marine agents contrasts strongly with that of atmospheric agents. While the latter deeply carve the surface into hills and valleys, and otherwise render it irregular, the former act as a huge scythe, mowing the rocks before it, and tending to produce great level plains.

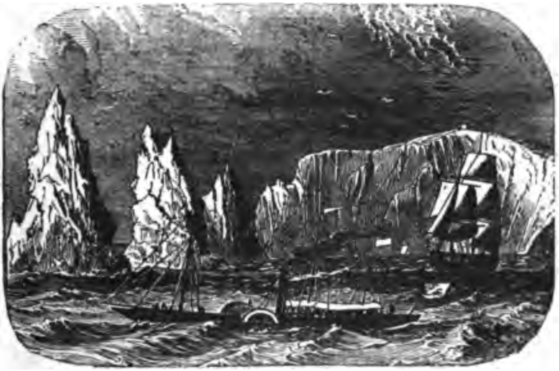

Fig. 12.—The Needles, Isle of Wight, showing effects of marine denudation.

The origin of the main irregularities of the coast-line, such as bays and headlands, must be attributed to marine action. The headlands, consisting of more durable rock, have withstood the encroachment of the sea to a much greater extent than the softer rocks which filled the bays. A good example is offered by St Bride's Bay, where the north and south promontories are formed of hard igneous rock, while the coast between them consists of the softer coal-measure strata.

CHAPTER VII.

TRANSPORTATION OF ERODED MATERIAL AND DISTRIBUTION OVER THE SEA-BOTTOM.

80. Transport of Eroded Material by Rivers.—Moving water and moving ice are great agents of transportation as well as of erosion. They destroy rocks, and, at the same time, carry the detritus away. Water is inferior to ice in its power to carry forward huge masses of rock; but its transporting power increases enormously with its velocity, and with very high velocities, immense blocks of stone may be moved forward, which slower currents would be unable to disturb. The buoyancy of water on bodies immersed in it materially assists its power to transport heavy mineral matter.

Brooks and rivers, with ordinary velocity, roll pebbles, gravel, sand, etc., along their bed, and carry mud, and sometimes fine sand, in suspension, the coarseness and amount of matter so carried increasing with the velocity of the stream. If a tumbler be filled with river-water, and allowed to stand for a short time, the suspended particles will be deposited, and will give some idea of the vast amount of matter carried to the sea by rivers.

On boiling to dryness a flask full of river-water free from sediment, it will be found that a considerable solid residue is left, consisting of matter previously held in solution by the water. Rivers carry considerable quantities of mineral matter in solution, such as bicarbonate and sulphate of lime, common salt, salts of magnesia, potash, etc. (61, 62).

The amount of detritus transported by large rivers, such as the Mississippi, Nile, Ganges, and others, is enormous. The Ganges, for instance, discharges into the sea every year 6368 millions of cubic feet of solid matter. This, if deposited evenly on a square mile of surface, would raise it 225 feet.

81. Deposition of Detritus in Quiet Water.—When a river loaded with suspended matter has its velocity checked, as when flowing through a lake or over a flat district, its power to transport is lessened, and more or less of the suspended matter is deposited as sediment. The Rhine and Rhone each flow into lakes (Constance and Geneva) as muddy rivers, fed by Alpine glaciers. In traversing the lake, all the suspended detritus is deposited, and the rivers leave the lakes as clear streams.

Deposits made in lakes are called *lacustrine*,[1] and lakes may, in time, become filled up by these deposits.

Rivers which overflow their banks deposit mud and gravel along their course, and these alluvial deposits, as the valley deepens, and as the river winds about, are cut into, giving rise to river terraces (76).

Rivers deposit their sediment on reaching the sea. If the velocity of the current is small, and powerful tides are absent, this deposition will take place at the river's mouth, and will tend to choke it up. This action produces, in time, great plains and marshy flats, through which the river makes its way by many channels. Such a formation is called a *delta*. The continual deposition of matter at the many mouths of the river increases the extent of the delta, and it gradually encroaches on the sea. The Rhine, Nile, Ganges, and Mississippi present familiar examples of deltas. The area of the latter is about 12,300 square miles.

Rivers in which the current is rapid, or which are subject to powerful tides, do not form deltas, the suspended material being carried out to sea by the force of the current, and there deposited, the heavier particles falling nearest the land, while the lighter portions are carried further out. When ocean currents sweep past the mouths of rivers, the lighter suspended particles may be carried to great distances before they finally subside.

The accumulations on sea-beaches are usually shingle and sand; farther out, sand only, the sand at length giving place to mud; while, in the open ocean, far away from land, dredging instruments bring up little more than the calcareous and siliceous remains of marine animals. Thus there are forming in the sea distinct beds of shingle, sand, mud, calcareous matter, and various mixtures of these. Alterations in the form and elevation of land, direction and force of rivers and ocean currents, disturb the distribution of sediments, so that mud may in time be thrown down upon sand, sand upon pebbles, and pebbles and sand may form beds where calcareous deposits were before accumulating. These processes, continued for ages, give rise to great piles of beds, alternating in their mineral character; and these, when hardened and elevated, form the rocks of the land, which, in their turn, are disintegrated and destroyed.

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[1] Lat. *lacus*, a lake.

CHAPTER VIII.

ORGANICALLY AND CHEMICALLY FORMED ROCKS—CONSOLIDATION OF STRATA.

ORGANICALLY FORMED ROCKS.

82. Marine Limestones.—It has been explained in previous articles (62, 80) that all calcareous rocks forming part of the land are continually subject to the solvent action of water containing carbonic acid in solution, the bicarbonate of lime resulting from this action being received into the rivers, and by them delivered to the sea.

Notwithstanding the vast quantities of carbonate of lime which reach the sea, this substance can scarcely be detected in sea-water. This is not surprising when we think of the profusion and endless variety of animals which live in the sea, and which require a large supply of carbonate of lime wherewith to form their shells, bones, and other hard parts. These animals abstract carbonate of lime from the sea-water, and form their skeletons with it. When they die, their calcareous remains accumulate at the sea-bottom, forming beds of limestone, more or less pure, according to their freedom from the detritus of the land. These accumulations, going on for long ages, give rise to limestone beds of great thickness, such as now form part of the land in many places.

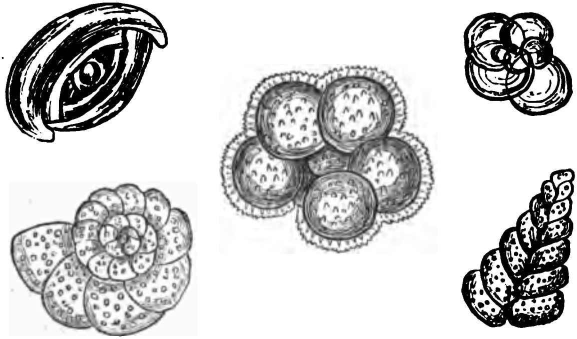

Fig. 13.—Calcareous shells of *foraminifera* (magnified).

The animals which contribute the greater portion of the material to form marine limestones are very minute in size, and simple in structure, but are protected by elaborately-formed cases or shells, composed of carbonate of lime, which they secrete from the sea-water. These minute animals are called *foraminifera*,[1] because the walls of their shells are perforated by many little tubes or passages. The *foraminifera*, although very minute, make up in numbers what they want in size. Some seas swarm with them, and considerable accumulations of their remains are taking place at the bottom of all such seas. In the mid-Atlantic the bottom is found to consist of a white adhesive mud, or ooze, which is made up almost entirely of the remains of *foraminifera.* When ordinary chalk is examined under the microscope, it is seen to be mainly composed of *foraminiferal* shells. This leads to the conclusion that strata of chalk were formed in a similar way to that in which the calcareous ooze of the Atlantic and other seas is now forming.

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[1] Lat. *foramina*, a passage; *fero*, I bear.

The coral polyp, which resembles the sea-anemone in structure, but is usually much smaller, contributes largely to the formation of limestone. It remains fixed the whole of its life upon a kind of stem (commonly known as coral) composed of carbonate of lime, and which each animal helps to form. As the animals die one by one, others take their place, and continue to make the *coral* larger. Coral reefs, which are abundant in the warm seas of the Indian and Pacific Ocean, have been formed by the gradual secretion of carbonate of lime by many generations of polyps. The coral polyp cannot live unless covered with water; but the reefs approach so near to the surface, that they are subject to the destructive action of sea-breakers, especially during storms. Fragments and particles of coral are continually detached, and deposited in the adjacent seas.

Much of the coral detached by the breakers is thrown forward, and piled up above high-water mark. These accumulations in time become compacted by the filling up of the vacant spaces with coral detritus, and form *coral islands,* which in many cases are covered with vegetation, and inhabited by men and animals.

Sea-lilies or encrinites, furnish calcareous remains in some seas. These animals are related to sea-stars and sea-urchins; but are fixed to the bottom of the sea, where they live, by long jointed stems consisting of carbonate of lime. These stems may accumulate to such an extent as to form thick beds of limestone. The encrinital limestone of Derbyshire consists in some places almost entirely of encrinital stems mingled with sea-shells and coral.

Shell-fish, such as oysters, mussels, etc., are so abundant in some places as to form calcareous beds of great extent by the accumulation of their shells.

83. Organic Siliceous Deposits.—Many minute organisms, found both in fresh and salt water, are provided with coverings of silica.[1] Polycistinæ (animals) and diatomaceæ (plants) are the most abundant; and these exist so plentifully in some lakes and seas, as to give rise to extensive deposits of silica. The polishing stone known as "tripoli" is composed entirely of the siliceous remains of microscopic organisms.

84. Coal.—When thin slices of coal are examined under the microscope, traces of vegetable tissues can in most cases be made out; more especially indications of spores and spore cases of club mosses and other cryptogamic (flowerless) plants. This points to the vegetable origin of coal, and the indication is supported by the numerous fern leaves, stems, bark, and other parts of plants which are found in, and associated with, coal. The chemical composition of coal also shows its relation to vegetable matter; coal, like wood, consisting of carbon, hydrogen, and oxygen, together with some earthy substances, which constitute the ash in each case.

When vegetable matter is exposed to moisture, but excluded from air, chemical changes set in, and it loses carbonic acid and water, becoming converted into peat. In this way peat is forming in many wet, boggy places at the present time, principally from the growth of mosses; but which, in their accumulation, often bury shrubs and fallen trunks of trees. Losing more carbonic acid and water, peat passes into lignite (30). Still losing carbonic acid and water, and in addition marsh-gas,[2] lignite becomes coal, that is, ordinary bituminous or house coal. A further loss of carbon and hydrogen converts coal into the stony mineral called anthracite (32).

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[1] The same chemical substance of which quartz is composed.

[2] A compound of carbon and hydrogen, the fire-damp of the coal-miner.

We gather from what has been said, that in the mineralisation of vegetable matter, there is, under favourable circumstances, a gradual passage through the conditions of peat, lignite, and bituminous coal, to anthracite. In some thick peat mosses, the peat at the top passes insensibly into a kind of lignite at the bottom; and in the same seam of coal, it sometimes happens that the upper part is bituminous, while it passes by degrees into anthracite in the under part.

The manner in which coal *beds* are formed will be explained further on.

CHEMICALLY FORMED ROCKS.

85. **Rock-Salt.**—Beds of rock-salt represent the sites of original salt lakes, such as now exist in many parts of the world. The Dead Sea is a good example. In some of these lakes (which have no outlets), the water is completely saturated with salt, and is ever receiving more; and as the bulk of water in them remains about the same (evaporation keeping pace with the supply), there is a continual deposition of salt going on, which in time may become thick beds, and at length, when some change in the conditions of the district ensues, be covered up by detritus. It may also happen to any salt lake that, from some change of level in the surrounding country, streams of water cease to flow into it, when it will be gradually dried up, leaving a bed of salt, more or less pure, at the bottom.

86. **Gypsum Beds** have a similar origin to that of rock-salt. Sulphate of lime, being soluble only to a small extent in water, would be deposited by a lake continuing to receive more when already saturated with it, and all would be deposited in the event of such a lake drying

up. Beds of gypsum, when they occur, are usually associated with other lacustrine strata.

87. Calcareous Deposits.—Deposits of carbonate of lime may be formed in lakes in a similar way to that in which rock-salt and gypsum are formed, giving rise to *fresh-water limestones.* Animals living in these lakes would contribute their hard parts towards the formation of such limestones.

Calcareous deposits also occur when water containing bicarbonate of lime in solution loses some of its carbonic acid. This is the case when water, after having percolated through calcareous beds, becomes exposed to the air, as when it reaches the roof of a cavern and drops from it. The drop of water, as it remains suspended from the roof, loses carbonic acid, and deposits carbonate of lime. The amount deposited by one drop may be very minute; but the process being incessantly continued, the slight projections first formed grow into long, pendant, icicle-like masses called *stalactites.*[1] The water which trickles down the sides of the cavern forms similar deposits, giving a smooth surface to the walls. On the floor of the cavern also, if no stream flow over it, the escape of carbonic acid continues, and further deposition of calcareous matter takes place, enclosing and preserving bones of animals, and any other objects which may happen to be there. Immediately underneath the *stalactites*, the deposition of matter goes on rapidly, and projections rise from the floor, looking like inverted *stalactites.* These are called *stalagmites.*[2] Occasionally the *stalactites* and *stalagmites* meet each other, and form a pillar-like mass.

In limestone districts, the springs, when they emerge from the rocks, are often so highly charged with calcareous matter, that on reaching the open air they deposit it freely upon whatever objects come in their way. Such springs have received the popular name of *petrifying springs*, on account of their giving a stony appearance to

[1] Gr. *stalasso*, to drop.

[2] Gr. *stalagma*, a drop.

twigs of wood, moss, and other objects placed in them for some time. The objects themselves, however, are unchanged, this deposition of solid matter *on them* being very different from the true process of petrifaction or fossilisation, by which the *substance* of the objects themselves becomes stone, and which takes vast ages to effect (114). Springs, such as described, sometimes deposit carbonate of lime in considerable quantities, and there often occur in their neighbourhood great thicknesses of light porous rock, called *tufa* or *travertine,* which have been formed in this way.

88. **Consolidation of Strata.**—Before leaving the subject of the formation of stratified rocks, it will be well to consider the mode in which soft and loose strata, such as mud and sand, become consolidated into hard rock. Pressure, chemical change, and heat are the agents principally concerned in effecting this alteration.

Pressure.—It is possible, by intense artificial pressure, to make clay and other incoherent matter quite compact and hard; and it is not difficult to see how in nature sufficient pressure is obtained to effect the consolidation of strata. New matter is continually being added to that already collected at the bottom of the sea; and if the sea-bottom is undisturbed for a great length of time, beds of great thickness (groups of strata occur on the land thousands of feet in thickness) may be accumulated. When this is the case, the lower beds—those formed earliest—become pressed with the enormous weight of the beds above them, and this pressure continued for great ages is alone sufficient to compact loose sediments into hard stone. Strata are also subject to intense pressure when it happens that they are crushed together laterally, as they undoubtedly have been in many cases, their crumpled form bearing evidence of the fact. In such cases, the rocks are also compact and stony; but other forces than mere pressure appear to have been at work, for rocks of this description are generally metamorphosed.

Infiltration of water containing solid matter in solution through porous strata, may give rise to consolidation, by the solid matter being deposited among the particles, thereby acting as a cement between them. The substances which appear to act in this way as cementing material are silica, carbonate of lime, and oxide of iron.

Chemical changes among the constituents of the strata themselves, giving rise to new arrangements of the particles, end in the hardening of rocks. The conversion of vegetable matter into coal is an example of this. The *setting* of cements serves to illustrate the hardening of material by internal chemical changes.

Heat alone may produce consolidation by actual or partial fusion and subsequent cooling, thus giving rise to metamorphic or igneous rocks. It may also assist pressure simply by expanding rocks. The part, however, played by heat in the consolidation of rocks is chiefly in its setting up and sustaining chemical changes, in which water usually takes an important part. Rocks hardened under the influence of heat, especially if water be present to assist in the rearrangement of the constituents, generally become crystalline; they are then said to be metamorphosed.

By the separate or combined action of the above mentioned agents—

Sand becomes	Sandstone.
Pebbles, ...	Conglomerate.
Angular fragments, ...	Breccia.
Mud, ...	Shale.
Clay, ...	Shale and slate.
Calcareous deposits, ...	Limestone.

89. **Summary.**—The last five chapters have been devoted to a detailed account of the various natural processes involved in the production of stratified rocks. We have seen that these rocks are formed, not of any essentially new material, but are derived from rocks already existing. Thus, for every cubic foot of matter accumulated at the sea-bottom, a cubic foot of the land is removed.

Evidently this process, if continued with no counteracting causes, would, in lapse of time, reduce all the land to submerged banks; but the very existence of sedimentary rocks now forming dry land, demonstrates the existence of forces capable of lifting the sea-bottom quite out of the water, and converting it into dry land, thereby counteracting the destructive action of denudation. The natural causes concerned in changing the level of land will next claim our attention.

CHAPTER IX.

CENTRAL HEAT OF THE EARTH—ORIGINAL FLUIDITY—VOLCANOES.

90. Central Heat of the Earth.—We shall now consider certain facts which lead to the conclusion that the earth is highly heated in the interior. Proofs are afforded by—(1.) temperature of mines; (2.) temperature of water from deep wells and hot springs; (3.) volcanoes and intrusive igneous rocks.

Temperature of Mines.—The changes of temperature accompanying the progress of the seasons do not affect the surface of the land to any great depth. In our latitude we reach a constant temperature at the depth of 60 or 70 feet at most. At any spot below this limit of variable temperature, a thermometer stands at the same height all the year round. In descending mines, after reaching a constant temperature, the rocks get warmer the lower we descend. This is true of all mines, wherever they occur, and whatever be the nature of the rocks in which they are situated. The rate at which the temperature increases with the distance descended varies in different mines, and at different depths in the same mine. The average rise of temperature is about 1° Fahr. for every 60 feet descended below the limit of variable temperature. In the Dukinfield coal-pit, near Manchester, a constant temperature of 51° Fahr. is reached at the depth of 17 feet. At the pit bottom, 2151 feet from the surface, the temperature is constantly 75° Fahr., showing an increase of 1° Fahr. for every 89 feet; less than the average. In sinking the Rosebridge colliery, near Wigan (now the deepest mine in Great Britain), very careful observations were made of the temperature of the rocks themselves during the progress of the work. The result gave 1° Fahr. as the rate of increase for every 54½ feet descended; the temperature at the depth of 806 yards being as high as 93½° Fahr.

Artesian Wells consist of borings, usually of great depth, in places where, from the nature and position of the strata, the water finds its way through the boring to the surface. The water of these wells is always warmer than the mean surface temperature, and the temperature increases with the depth. An artesian well at Grenelle, near Paris, is 1798 feet deep, and the water has a uniform temperature of 81·7° Fahr. *Hot Springs* are usually connected with great fractures and dislocations in the rocks, extending to great depths.

Volcanoes, during their periods of activity, pour out streams of molten lava, and eject other heated matter. The very general distribution of volcanoes, recent and extinct, the vast amount of matter thrown out by them, and the highly-heated state of this matter, shows the existence of a widely-spread source of intense heat beneath the surface.

Igneous Rocks, which occur every here and there at the surface, imply the existence of heat to melt them; and when it happens that they are really intrusive rocks which have undoubtedly been melted,—such as basalt or greenstone,—they point to the source of heat being below them (44).

Other proofs may be adduced, but the above are quite sufficient to establish the fact that the interior of the earth is in a highly heated state.

Supposing the increase of temperature to go on at the observed average rate, at the depth of three or four miles the temperature of boiling water would be reached; at 50 miles the heat would be great enough to melt steel; while at 100 miles the temperature would probably be sufficiently high to fuse all known rocks. But whether the rocks are in an actual fluid state, at this or greater depths, is at present purely a matter of theory.

91. **Theory of Original Fluidity of the Earth.**—Without going into details, it may be stated that the observations of astronomers have led to the belief that the earth was once (in common with the other members of the solar system) in a nebulous or gaseous condition, from which it condensed to an intensely-heated globe of liquified matter. Radiation of heat taking place, it at length became sufficiently cool to allow the surface to consolidate, forming an exterior shell or crust. Continued radiation thickened this crust, and so far cooled its surface, that the water, previously existing as an atmosphere of steam, was at length able to remain on it, thus commencing the condition of things as they exist at present. The spheroidal form of the earth, being such as would be assumed by a liquid or semi-solid body rotating on an axis, together with the facts considered in the last article, all support the theory of the original fluidity of the earth.

We have little or no positive knowledge of the present condition of the earth's interior. Some have supposed it to be quite liquid, and having but a thin crust. It would seem, however, that the crust must be very thick in order to withstand the action of the tides which would be produced in the fluid matter, supposing it to exist. It is likely, also, that as the earth cooled, and while it remained sufficiently liquid for convection to take place, the pressure at the centre was more powerful in promoting solidity than the heat in inducing liquidity, and consolidation would, therefore, commence at the centre. When, however, the liquid mass which surrounded the solid nucleus became too viscid to allow of convection, then a crust would begin to be formed on the exterior. We can imagine the space between the two zones of solidification to consist of a honeycombed structure containing detached masses of fluid matter (from whence volcanic products may be derived). This would give us a rigid earth, and just what astronomy requires it to be; for if not rigid, it would give rise to motions which could easily be detected.

92. Volcanoes.—Every one is familiar with the general appearance of a volcano, from the frequency with which volcanoes are figured. At the top of the volcano is a cup-like depression or *crater*, which is the upper expanded portion of a funnel or passage communicating with the molten matter below, and by which the products of the volcano reach the surface during an eruption. On the flanks of the main cone there are usually a number of smaller cones, each with its own crater, and fed by branches from the main funnel. As many as 600 minor cones appear on the sides of Etna.

Frequently the first signs of the eruption of a volcano are earthquakes, which may continue more or less during the period of activity. The eruption usually commences by the ejection of steam and other vapours, followed by an effusion of lava into the crater, where it boils up, giving rise to ashes, and often overflows the lip of the crater, or forces a passage through the sides, and runs in streams down the slopes of the mountain.

During periods of repose, the slumbering volcano often gives evidence of being still in connection with heated matter, by emitting volumes of smoke (really fine ashes and steam).

The conical pile of matter constituting a volcano has all been ejected by the volcano itself, and the cone-like form is the necessary consequence of the continual addition of ashes to the summit of the mountain; just as a mound of sand or other loose matter takes a similar form when fresh material is continually added to the top of it.

The particular slope depends on the amount of friction between the particles of the material. Some volcanoes have as great a slope as 45°, but 30° is about the average.

From observations in denuded volcanic districts, much information has been derived with regard to the internal structure of volcanoes. An imaginary section through a volcanic cone is given in the figure.

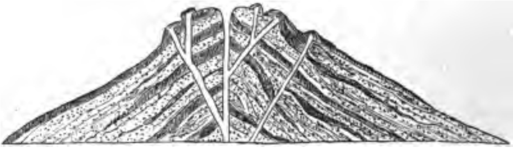

Fig. 14.—Imaginary section through a volcanic cone. The darker portions represent lava streams.

In some places, as in the Puy de Dôme district of central France, groups of volcanic cones occur, with their craters and old lava streams, but which have never been in a state of eruption, or even emitted vapours, in historical times. Such cones are called extinct volcanoes.

Volcanoes may exist at the bottom of the sea, when they are called *submarine*.

CHAPTER X.

MOVEMENTS OF THE EARTH'S CRUST—MOUNTAIN CHAINS—METAMORPHISM.

93. Movements of the Earth's Crust.—The fact that the greater portion of the land consists of strata made up of waste matter accumulated at the bottom of old seas which existed on the spot where these rocks are now found, is sufficient evidence of a change of level, either of the sea or the land, having taken place since the deposition of the strata in question.

That it is not the sea-level which has changed we may rest assured, for if the level of the sea should be lowered a few feet in one place, it must be lowered an equal amount all over the earth, and we cannot conceive of any occurrence of sufficient magnitude to effect this. Again, the quantity of water on the earth being always the same, there can be no alteration of its level without some change in the form and size of its rocky basin, which at once implies movements of the earth's crust.

Not only have we old sea-bottoms forming dry land, and raised beaches, with their shingle and shells, of more modern date, but in many places, and even on our own coasts, forests, and sometimes buildings, occur submerged by the sea. Of course these forests have changed wonderfully in appearance; the branches and the greater part of the stems are gone, but the stumps may be observed projecting out of the sea-bed at very low water.

The movements to which the crust of the earth is subject are principally of two kinds—(1.) Oscillations due to earthquakes, which generally effect permanent alterations in the level of the land; and (2.) Slow and gradual movements of elevation and depression.

Elevation is more frequent than depression, and in this way serves to compensate for the destruction of the land by marine and atmospheric erosion. Without elevation, the time would certainly come when all the land (except coral reefs) would disappear below the surface of the sea.

94. Earthquakes.—An earthquake in its typical form consists of a sudden heaving of the land, which sinks again immediately, the protuberance thus formed moving forward with great velocity in all directions, in a manner that may be compared to the motion of a wave on the surface of water. The intensity of the shock is greatest at the place first disturbed, from which spot it gradually decreases to the more remote districts, where the effect dies away. Sometimes a succession of waves occur, each of which traverses the disturbed country with great velocity.

When the earthquake-wave originates beneath the sea, and travels towards the land, a huge sea-wave is formed, which does not keep pace with the earthquake-wave, but comes in after the latter has subsided, sweeping over the land, and often effecting as much destruction as the earthquake itself.

There is undoubtedly a relation between volcanoes and earthquakes. The latter are more frequent in localities where the former are numerous. The eruption of a volcano is often preceded, and accompanied, by earthquakes.

Great earthquakes are fortunately very rare; but shocks of lesser intensity are frequent. It is calculated that an earthquake occurs every week on an average, in some part of the world or other. Our own islands do not escape occasional shocks.

95. Permanent Alterations of Level accompanying Earthquakes.—Many cases have occurred where the oscillations of the land during earthquakes have resulted in permanent alteration of level. The west coast of South America abounds with instances of this kind. In many parts of this coast sea-beaches are found at various heights above the sea-level. These beaches are often known to be of modern date by the fresh state of the shells. We are furnished with accounts of many upheavals and depressions accompanying earthquakes. During the earthquake of Conception in Chili in 1835, a belt of coast was raised five or six feet, and after slowly subsiding, remained at an elevation of two feet above the original level.

96. Slow Elevation and Depression.—Observations in various parts of the world show that many tracts of land are slowly subsiding, while others are gradually rising. We need not go far to arrive at districts where elevation is actually taking place. The Scandinavian shores of the

Baltic afford a good instance. Observations in this sea (facilitated by the almost entire absence of tides) show that the whole coast from Stockholm northwards is slowly rising. The rate increases from a few inches in a century a little north of Stockholm, to 5 or 6 feet in a century in the district of the North Cape. An instance of slow depression is afforded by the west coast of Greenland, where for a distance of 600 miles the shore is slowly subsiding. Posts to which boats were formerly moored, and the remains of habitations, are found beneath the water in many parts of this district.

97. Depression proved by Coral Reefs.—The manner in which coral reefs are produced by the coral polyp has already been described (82). Coral reefs are of three principal kinds—*fringing reefs*, *barrier reefs*, and *atolls*.

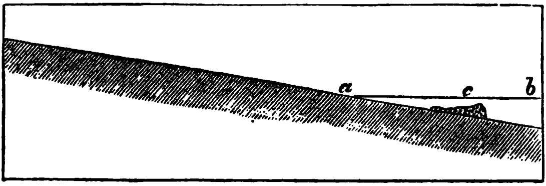

Fig. 15.—Diagram of a fringing reef (c).
a b Level of the sea.

Fringing Reefs.—The reef-building polyp can only live in warm, clear sea-water of a certain moderate depth. In the Indian and Pacific Oceans these conditions are afforded by the shallow water near the rocky margins of numerous islands and continental shores. Wherever the conditions are favourable, the land is fringed, at some little distance from the shore, with reefs of coral called fringing reefs, the growing portions of which are always below water.

Barrier Reefs are great reefs of coral, which occur quite away from the mainland, generally running parallel to the coast, but frequently at a distance of many miles from it. Between the reef and the land the water is comparatively shallow, but sufficiently deep to float large ships, while the outer edge of the reef descends almost vertically into deep, and often unfathomable water. The best example of a reef of this kind is the great barrier which stretches in a broken line along the north-east of Australia for more than 1000 miles, and at about 50 or 60 miles from the shore.

From what has been said of the habits of the coral polyp, it is evident that the barrier reef could not have been commenced at the great depth below the surface of the sea to which they are known to descend. The origin of these reefs is accounted for in this way:—The barrier reef was once a fringing reef skirting the shores of the land in a district undergoing slow depression. In consequence of this depression the sea gradually encroached upon the land, and removed the coast line backwards, while the movement was sufficiently slow to allow the polyps, in their efforts to maintain their proper depth by continually growing on the top of the reef, to keep it at the same level below the sea. This will be made clear by referring to the diagram, Fig. 16, which is intended to represent a barrier reef formed by the growth of the fringing reef in Fig. 15, the land being supposed to be lowered.

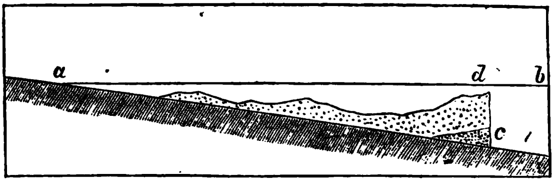

Fig. 16.—Diagram showing the formation of a barrier reef (*d*). *c* Original fringing reef. *a b* Present sea-level.

Atolls.—When barrier reefs entirely surround an island, they are called *encircling reefs.* Should the depression of an island with an encircling reef be continued, slowly enough for the coral polyps to raise their reef as the island sinks, it may happen in time that the island will quite disappear below the water, while the reef remains at the surface in the form of a huge irregular ring. Many ring-like reefs occur in the Pacific Ocean, and are called *atolls*. Like barrier reefs, they present steep fronts to deep water without, while on the inside they gradually slope to the bottom of the included *lagoon*, the depth of which is much less than that of the sea outside the reef.

98. Elevation proved by Coral Reefs.—Coral reefs are sometimes useful in proving *elevation*. In some districts, mostly volcanic, old coral reefs are found on the coast high above the present sea-level. In all cases they are much eroded, and often recognised with difficulty. Reefs of this kind occur in Java and neighbouring islands.

99. Probable Cause of the Movements of the Earth's Crust.—It is generally thought that the slow movements of depression and elevation are consequent on the contraction of the earth by cooling. The earth continuing to cool after the crust was formed, and gradually contracting in bulk, would tend to retreat from the solidified crust, leaving a space between it and the still liquid sphere within. But the crust, being drawn down by gravity, would, by bending and crumpling, adapt itself to the ever-decreasing surface. The movements of the crust would not, of course, take place all at once, but would be of all ages. The movements taking place at the present time are probably due as much to the gradual yielding of portions of the crust which have not yet thoroughly settled down into a stable position, as to the cooling going on at the present time, which is comparatively slow.

100. Mountain Chains.—It has already been explained that mountains and hills are often the work of atmospheric denudation (74). Mountain *chains*, however, while they have been subject to extensive denudation, giving rise to peaks, passes, and other mountain scenery, owe their origin in the first place to actual elevation. Several theories have been proposed to account for their elevation, the most probable explanation being, that they were formed during the efforts of the earth's crust to adapt itself to the shrinking mass within, as just explained. In this way, while large tracts quietly subsided, the less rigid or weaker portions were thrown into folds or ridges, of which our mountain chains are the remnants. The condition of the skin of a shrivelled apple illustrates the crumpling of a covering in its efforts to adapt itself to a shrinking mass.

The general structure of mountain chains favours this view. On either side the strata dip away from the axis of the mountain, showing that they have been thrown up into anticlinal curves. Frequently, also, the central portions of the mountain chain consist of granite or highly metamorphosed rocks; and these, by their superior resistance to denuding forces, are left at comparatively high levels, forming the rugged peaks which characterise so many mountains. In the present state of our knowledge, we cannot positively say whether the granite found its way up in a melted state from below, when the mountain range was formed, and thus by its heat helped to metamorphose the adjacent strata; or whether the heat produced by the lateral crushing together of the strata to form the foldings was not sufficient to metamorphose the internal strata, even to the formation of granite.

101. Metamorphism.—Closely connected with the subjects of the interior heat of the earth, and the movements of its crust, is that of metamorphism. This is an important change which stratified rocks are capable of undergoing, and which so completely alters the chemical arrangement of their constituents, that they lose their original texture, and become more or less crystalline, often resembling igneous rocks, for which they are sometimes mistaken. Frequently the crystals assume the form of mere plates, lying flatly one upon another, giving a laminated structure to the rock, but the lamination is not necessarily parallel to the stratification (*see* 19, 33, 35).

Cleavage, both slaty and schistose, is due to pressure. The flattened fossils which are found in slaty rocks are evidence of this, and the structure can be produced in many substances artificially. If a piece of soft wax be strongly compressed between two opposite surfaces, it acquires a laminated structure, the cleavage being perpendicular to the direction of the pressure.

Schistose and slaty rocks occur for the most part in the contorted and crushed rocks which form mountainous districts, and we have to look for the pressure producing the cleavage and foliation in the lateral forces which produced the crumpling of the rocks.

Heat is undoubtedly a principal agent in the metamorphism of rocks. We know how the potter's clay is baked by heat into porcelain; and we should expect to find rocks subjected to great heat to have undergone somewhat similar change. In speaking of igneous rocks it has already been stated, that wherever these penetrate sedimentary strata, the latter become much altered from the baking they have undergone.

It would seem that, from the considerable rearrangement which has taken place among the chemical constituents of metamorphic rocks, some solvent power, such as that of water, must have been at work; and it is known that water, when intensely heated under great pressure, will dissolve quartz and many other minerals ordinarily insoluble.

Examination of synclinal curves shows the strata in many cases to descend to great depths, probably within the reach of great internal heat. In this way many rocks have been metamorphosed, and have since been exposed by denudation, or by elevation and denudation combined. The heat developed by the lateral crushing of rocks as a probable cause of metamorphism, in some cases, has already been referred to.

By metamorphic action, sandstones become quartz rock, shales are changed into mica schist, clay and slate into gneiss, and limestone into crystalline limestone or marble.

It was originally thought that metamorphism was confined to the oldest rocks only. Doubtless these have been subjected to the conditions of metamorphism many times, and are likely to be more completely metamorphosed than younger rocks; but observations show that metamorphic rocks may be of any age.

102. Lodes.—Many of the older rocks are traversed by irregular veins of metallic ores, and other mineral matter, called *lodes.* A lode appears to have been originally a fissure, and this has subsequently become filled by the deposit of various mineral matters. The substances most commonly found in lodes are quartz, carbonate of lime (calc spar), carbonate and sulphate of copper, sulphide of lead (galena), oxide of tin, etc. It is not very clear how the lodes became filled with these substances; but it is probable they were deposited from water containing them in solution, as it flowed through the fissures. They were formed in all cases at great depths, where the temperature and pressure would greatly aid the solvent power of water.

CHAPTER XI.

POSITIONS OF ROCKS.

103. Positions of Rocks.—We began our study of rocks with an examination of their mineral peculiarities; we then followed step by step the natural processes concerned in the production of new rocks; and finally considered those forces which produce great change in the position and internal constitution of the strata on which they act. In this chapter we shall return to the rocks themselves, and study the various positions in which they lie, and the relation they bear one to another. This will afterwards render important help in the study of geological history.

104. Maps and Sections.—In order to understand the geological structure of any district, it is necessary to study the surface, and trace the boundary lines of the different kinds of rocks appearing at the surface; it is also necessary to examine sections or cuttings through the rocks, which show the inclination of the strata, and their relation one to another.

By means of maps, the nature and extent of the rocks at the surface may be shown, and sectional drawings may be made to exhibit the inclination and relative position of the beds. The different rocks may be distinguished, either on maps or sections, by varieties of shading and marks; but it is found more convenient on maps to distinguish them by colours, as this allows of the marking on the maps of the names of rivers, towns, roads, etc. In geological maps, the colours selected have usually some relation to the prevailing tint of the rock they represent.

105. Horizontal and Inclined Strata.—These terms explain themselves. Fig. 17 represents a group of horizontal strata, and Fig. 18 inclined strata. By inspection of Fig 18, it will be seen that while strata are inclined in one section, they may appear to be horizontal in another section.

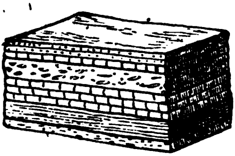

Fig. 17.

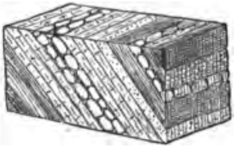

Fig. 18.

Strata of all inclinations occur, and in some cases they are even *vertical*, or on *edge*. Further than this, instances are known where the strata are actually *inverted*.

106. Outcrop—Strike.—The exposed edges of strata, where they come to the surface, is called their *outcrop;* and we are accustomed to say such and such a bed *crops out* at such and such a place. Miners call the outcrop of a stratum its *basset edge*.

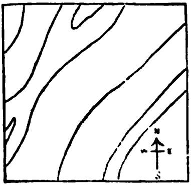

Fig. 19.

The direction in which the line of outcrop or basset edge of a bed lies, stated in the points of the compass, is called its *strike*. Thus, in the imaginary map, Fig. 19, the general strike of the beds is NE. and SW.

107. Dip—Clinometers.—The angle at which a bed is inclined to the horizontal is called its dip. This, of course, is the angle through which the bed has been tilted from its original position.

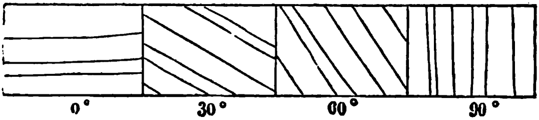

Fig. 20.—Examples of dip.

The dip of a bed must be determined in a section at right angles to the strike. The reason for this will be made clear on inspecting Fig. 18. In this diagram the section to the left hand shows the true dip, while in that to the right the strata appear to be horizontal.

To measure the dip of strata, we require an instrument called a *clinometer*. The beginner would do well to construct a simple one for himself, and to make use of it in determining the true or apparent dip of strata in his own neighbourhood. A simple form of clinometer is shown in Fig. 21. It may be constructed of a piece of thin board about six inches square, a small plummet being attached near one corner, and a graduated arc of 90° marked on the board. Placing the clinometer as shown in the figure, the plummet marks the dip. The measurement is more accurate if the clinometer is made to rest on the edge of a long lath with parallel edges, which is held parallel with the strata.

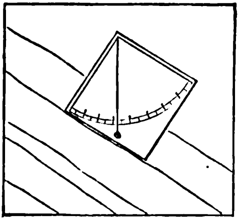

Fig. 21.—Clinometer.

108. Curved Strata.—Strata are often curved, and we have had frequent occasion to refer to curved strata. The curves may be of large radius, or be often repeated in the space of a few miles, or even yards. In curved strata the dip continually varies. Hence, if we examine the same series of beds in different places, and find the dip is not constant, we infer that the strata are curved.

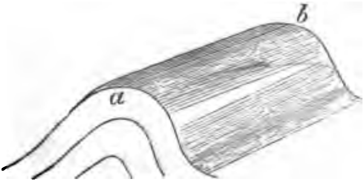

Fig. 22.—Anticlinal curve.
a b Direction of axis.

Anticlinal and synclinal curves (75) are great folds in the strata, and often extend to considerable distances in the direction of their axes, that is, in the direction of the length of the fold. When the strata of synclinal curves dip towards a line or axis, they form a *trough*. If they dip towards the same point, they form a *basin*. A vertical section through a basin shows a synclinal curve in whatever direction it is taken. It must be remembered that the terms "trough" and "basin" do not refer to depressions in the ground itself, but only to the curvature of the strata. Thus it happens sometimes that the strata forming a hill are synclinal. When the curvature of strata is very sharp, and often repeated in a small space, the strata are said to be contorted (Fig. 23).

109. Joints.—All consolidated strata are traversed by planes of division perpendicular to the stratification. These divisional planes, called *joints*, divide strata into cuboidal masses, giving them the appearance of having been built up of separate blocks, like the walls of a building. Igneous rocks are also cut by joints, but these are not usually so regular in form as they are in stratified rocks, except in the case of lavas having a columnar structure. Joints facilitate quarrying, and the subsequent fashioning of the stones. They owe their origin to the contraction of the rock during its consolidation.

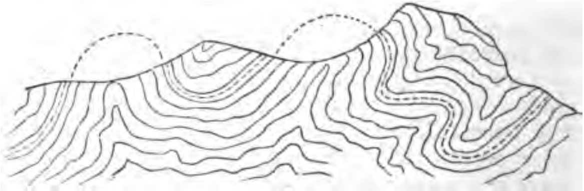

Fig. 23.—Contorted strata.

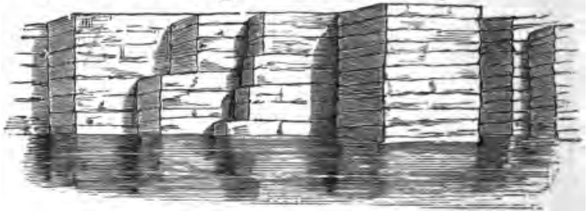

Fig. 24.—Joints in strata.

110. Faults.—It has happened sometimes that, during the movements of the earth's crust, strata have been actually broken through, and so displaced that they do not correspond on opposite sides of the fracture, those on one side having a higher elevation than those on the other. Such a fracture and displacement is called a *fault*. Coal-miners, in following some particular bed, find it suddenly terminate on reaching a fault. They have then to seek the continuation of the bed on the other side of the fault, at a higher or lower level; and they term the fault an *upthrow* or *downthrow*, according as they have to rise or descend. The same fault would be an upthrow or downthrow according to the side it were approached from.

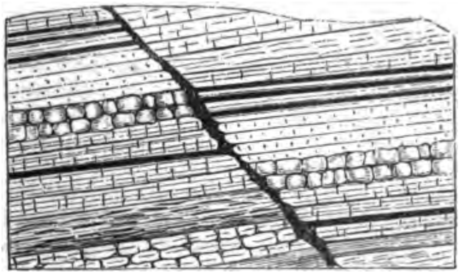

Fig. 25.—Fault.

111. Conformable and Unconformable Stratification.—When two series of strata lie parallel to each other, and there is no appearance of the first series having suffered denudation before the deposition of the second series, they are said to be conformable to each other. On the other hand, when one series of beds rests upon the denuded edges of another set, the two series are said to be unconformable to each other.

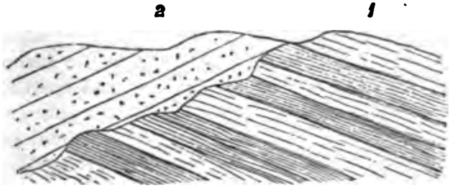

Fig. 26.—Unconformable stratification.

CHAPTER XII.

FOSSILS—CLASSES OF ANIMALS AND PLANTS.

112. Fossils.—The literal meaning of the word "fossil" is *something dug up;* but the term is now restricted to the remains of animals and plants, and impressions made by them, occurring in various rocks.

It is only the harder parts of animals which are found fossil, such as bones, teeth, scales, crustaceous coverings, coral, etc. The parts of plants most commonly found in the fossil state are leaves, wood, bark, and roots; more rarely fruits, seeds, spores, and spore cases.

The study of fossil remains is called *Palæontology.*[1]

113. Preservation of Animal and Plant Remains.—When animals or plants cease to live, chemical decomposition sets in, and their soft parts are speedily obliterated; even their bones or other hard parts, if sufficiently long exposed, crumble to dust. The operations of nature, however, frequently lead to the preservation of organic remains; in the first place, by covering them up, and afterwards converting them into stone, when they are saved from further decomposition, and often become as permanent as the rock in which they are embedded.

The following are some of the ways in which animal and plant remains become buried. Marine animals, as they die, fall to the bottom of the sea, and soon become buried by sedimentary matter; the same applies to animals living in lakes. The remains of terrestrial animals may be covered up by sand being blown over them, or by volcanic ashes falling on them, or they may in time be buried by the growth of peat-mosses. When rivers overflow their banks, the floods are often very destructive to animal life, and the bodies of animals may become buried by the silt left by the river, or they may be floated down to the river's mouth, and be enclosed in the deposits there. Remains of terrestrial animals are frequently found in alluvial deposits. The preservation of animal remains by their becoming enclosed in cave deposits has already been alluded to (87).

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[1] Gr. *palaios,* ancient; *logos,* an account of.

114. Fossilisation or Petrifaction.—Fossil animals and plants, while they retain their original form, have lost all or most of their original substance, it having been replaced by a slow and gradual process from the mineral matter in which the remains were embedded. It often happens that the chemical composition of the fossil is totally different from the matter which composed it originally. Thus shells, originally composed of carbonate of lime, are often found converted into iron pyrites (sulphide of iron), when they have been embedded in clay. Wood, enclosed in sandstone, is changed into silica, while in limestone it is often converted into carbonate of lime.

It must not be supposed that the process of fossilisation is one which can be watched or imitated, for it requires vast ages to accomplish it, and we find the change is not so complete in the fossils of the later rocks as it is in those of the older ones.

For a fossil to be perfectly formed, it is necessary that the material in which it is embedded should be free from substances which would act destructively on the organic structure, and it is further necessary that the rock be not pervious to water. In the case of sandstones and other strata which allow water to percolate through them, perfect fossils are not found, only casts and impressions of them.

115. Preservation of Footprints and other Impressions.—Animals, in walking over the wet sand, mud, or clay upon the sea-beach or margin of a lake or river, leave impressions of their feet; and if these marks are soon covered up with sand or mud, quietly strewn over them, as by the rising tide, they may be permanently preserved, especially if the soft surface of the ground has been well baked by the sun before receiving another layer. In a similar way are preserved worm tracts and burrows, ripple-marks, sun-cracks, and even the impressions made by raindrops. Fine-grained flagstones on being split, often exhibit ripple-marks, rain-pittings, and other such markings.

116. Nature of Deposits inferred from Fossils.—The nature of various strata, and the conditions under which they were deposited, can often be made out by an examination of their mineral character; but this is made far more easy by the study of their fossils.

Marine Deposits are known by their containing marine shells, corals, and other remains of animals which inhabit the sea. Deposits made in the neighbourhood of land may be told by their containing fragments of land plants, insects, and larger animals inhabiting the land.

Fresh-water Deposits are frequently recognised by their containing shells and bones of animals which only inhabit fresh water, and from the absence of all traces of marine life. The following shells, common in our ponds and rivers at the present day, are characteristic of fresh-water formations, viz.—*Planorbis, Lymnea, Physa, Paludina, Anodon, Unio.*

Estuarine Deposits often contain both marine and fresh-water species, mingled with forms which are peculiar to brackish water.

Old Sea-beaches can often be told by their beds of shells, as well as by ripple-marks, footprints, etc.

117. Classification of Animals and Plants.—Before proceeding to study the geological history of rocks, the student must make himself familiar with the great classes into which animals and plants are grouped. This is necessary, for the world's history is principally made out from the evidence afforded by fossil plants and animals.

Every distinct kind of animal or plant constitutes a *species*, and receives a *specific* name. When two or more species closely resemble each other, but differ in some modification of structure, they are grouped into one *genus* (pl. *genera*), and receive a *generic* name. To illustrate this, let us take as examples the rabbit and the hare.

There are many different breeds of rabbits, differing in colour, length of hair, shape of head, etc., but they have no essential difference in their internal structure. Popularly we call all these breeds *rabbits*, and scientifically we say they are all *varieties* of one species, and they receive the same specific name. The resemblance of the hare to the rabbit is striking, but at the same time we readily distinguish the one from the other by peculiarities of form, and these are connected with distinct modifications of structure. The hare and rabbit are therefore said to be distinct species, but belong to the same genus. They have both received the generic name *lepus;* the hare being *lepus timidus*, and the rabbit *lepus cuniculus.*

Closely related in structure to the rabbit and hare, we have the porcupine, beaver, rat, mouse, squirrel, and a number of other animals. These are grouped into one NATURAL ORDER called *Rodentia.*

A number of natural orders having in common the same modification of some important structure, as the skeleton, heart, or respiratory organs, form one CLASS.

Ultimately, all the *classes* are grouped into seven or eight SUB-KINGDOMS, the members of each sub-kingdom being built upon the same general plan.

What has been said of the grouping of animals into orders and classes also applies to plants.

CLASSIFICATION OF ANIMALS.

SUB-KINGDOM VERTEBRATA.

Animals with a vertebral column, or back-bone, composed of segments jointed together; each segment is called a *vertebra.*

The remaining sub-kingdoms are collectively called the *invertebrata.*

CLASS I.—*Mammalia,* or mammals. Warm-blooded viviparous quadrupeds, with skins more or less hairy, and giving suck to their young. Examples—lion, horse, whale.

Class II.—*Aves*, or birds. Examples—eagle, finch, ostrich.

Class III.—*Reptilia*, or reptiles. Cold-blooded quadrupeds with scaly skins (legs sometimes absent). Examples—crocodile, tortoise, lizard, snake.

Class IV.—*Amphibia*. Animals having gills like a fish in early life. Examples—frog, toad, newt.

Class V.—*Pisces*, or fishes. Examples—salmon, shark, eel.

SUB-KINGDOM MOLLUSCA.

Class I.—*Cephalopoda*. Molluscs with a ring of arm-like appendages (tentacles) round their head. Many secrete shells consisting of a series of chambers. Examples—cuttle-fish, nautilus, ammonite.

Class II.—*Pteropoda*. Molluscs which inhabit the open ocean. The clio, which is the principal food of the whale, is an example.

Class III.—*Pulmogasteropoda* (pulmata). Air-breathing molluscs, secreting in most cases a spiral shell, consisting of one piece (univalve.) Example—common snail.

Class IV.—*Branchiogasteropoda*. Molluscs respiring by means of gills, and having univalve shells, usually spiral. Examples—periwinkle, whelk, cowry, limpet.

Class V.—*Lamellibranchiata* (conchifera.) Molluscs with shells of two pieces (bivalve) hinged together. The two halves are usually like each other, but are right and left, like a pair of gloves, and correspond to the right and left of the animal. Examples—oyster, cockle, mussel, scallop, and all ordinary bivalves.

SUB-KINGDOM MOLLUSCOIDA.

Class I.—*Ascidioida*. Marine animals with soft bodies; not known in the fossil state.

Class II.—*Brachiopoda*. Have bivalve shells, the two halves being unlike each other, and correspond to the upper and lower parts of the animal. Examples—terebratula (lamp-shells), lingula.

CLASS III.—*Polyzoa.* Compound animals, usually residing on a branched stem, which each individual helps to form. Example—sea-mat (flustra).

SUB-KINGDOM COELENTERATA.

CLASS I.—*Actinozoa.* Examples—sea-anemone, coral polyp.

CLASS II.—*Hydrozoa.* Example—hydra.

SUB-KINGDOM ANNULOSA.

Animals with bodies in jointed segments.

CLASS I.—*Insecta* or insects. Examples—bee, butterfly, beetle.

CLASS II.—*Myriapoda.* Example—centipede.

CLASS III.—*Arachnida.* Examples—spider, scorpion.

CLASS IV.—*Crustacea.* Example—lobster, crab, woodlouse.

CLASS V.—*Annelida.* Examples—earthworm, leech.

SUB-KINGDOM ANNULOIDA.

CLASS I.—*Scolecida.* Examples—tapeworm, rotifer.

CLASS II.—*Echinodermata.* Examples — sea-urchin, star-fish, sea-lilies.

SUB-KINGDOM PROTOZOA.

CLASS I.—*Infusoria.* Microscopic animals living in water.

CLASS II.—*Spongida.* Example—sponges.

CLASS III.—*Radiolaria.* Microscopic animals, usually with silicified coverings.

CLASS IV.—*Rhizopoda.* Example—foraminifera.

CLASS V.—*Gregarinida.* Internal parasites.

CLASSIFICATION OF PLANTS.

SUB-KINGDOM PHANEROGAMIA.

Flowering plants, producing seeds containing the rudiments of the future plant (embryo).

Class i.—*Dicotyledones or Exogens.* Plants with two seed-leaves, net-veined leaves, and having their new wood packed outside that already formed, giving rise to the appearance of concentric rings in a cross section.

Sub-class.—Angiosperms. Seeds in a seed-vessel. Examples—all British trees but conifers; also buttercup, rose, convolvulus, nettle.

Sub-class.—Gymnosperms. Seeds naked. Examples—coniferæ (cone-bearers), as fir, larch, cypress, cycads.

Class ii.—*Monocotyledones or Endogens.* Plants with one seed-leaf, parallel-veined leaves, and having their new wood packed inside the stem. Examples—palms, bananas, aloe, lily, onion, rushes, grasses.

SUB-KINGDOM CRYPTOGAMIA.

Flowerless plants, producing spores containing no embryo.

Class i.—*Acrogens.* Ferns, equisetums (horsetails), lycopodiums (club mosses), and mosses.

Class ii.—*Thallogens.* Lichens, fungi (mushroom, toadstools, etc.), algæ (sea-weeds).

CHAPTER XIII.

Relative Age of Rocks.

118. Relative Age of Strata.—When one stratum rests upon another, we infer that the *lower* bed was completely deposited before the *upper* bed was commenced. Thus, in the three beds marked 1, 2, and 3, we know that 1 is the oldest, and 3 the newest. It is clear, also, that if fossils are found in 1, the animals or plants lived and died before 2 was deposited.

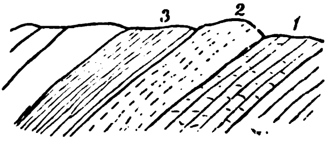

Fig. 27.

By observing how strata rest one upon the other in various places, geologists are able to make out the order of succession of stratified rocks, and to construct tables showing their *superposition*. These observations are much facilitated by the exposure of the edges of strata by denudation, especially where the strata are inclined.

If we confine our observations to rocks of the same age, we find that while some of the fossils are local, many are constant throughout, occurring wherever the rocks are found. In passing, however, to newer rocks, we find a change in the fossils; species which characterised the older rocks have disappeared, and have been replaced by others, many of which in their turn characterise these newer rocks. Thus we find that each age of the world had its own peculiar animals and plants, its *fauna* and *flora*. This "succession of life in time" having been established, and having a knowledge of the fossils which characterise the different periods, we are able to discover the geological age of many strata, even when we cannot trace their superposition.

Rocks of the same age have often peculiarities in their *mineralogical structure*, and may sometimes be recognised in distant places by this means alone.

It sometimes happens that we can tell which is the older of two series of strata, by one series containing fragments derived from the waste of the other series.

119. Geological Time.—In the structure of the earth we have everywhere evidence of the lapse of great periods of time. It has been ascertained that if all British strata were superposed in chronological order, it would make an aggregate thickness of nearly twenty miles. All this has been slowly accumulated in a similar manner to that in which beds of sand, mud, and ooze are now accumulating in lakes and in the sea; hence a vast duration of time is represented by the strata alone.

The change from one bed to another of a different kind also represents time. For instance, if we find a bed of conglomerate resting on one of limestone, we know that an interval of time must have elapsed, unrepresented by deposition, during which interval the movements of the land, or other causes, gave rise to altered conditions in the district. We must not forget that intervals at one place may be represented by actual strata at another.

Unconformable stratification implies the lapse of a long interval of time between the deposition of the two series of beds. Thus, in Fig. 26, it is clear that after the beds marked 1 had been deposited, they must have been elevated, denuded, and again depressed, before the deposition of the series 2.

120. Change of Species in Relation to Intervals.—It has already been said that each age of the world has its own peculiar animals and plants, and, consequently, the rocks of different ages are characterised by peculiar fossils of their own. When we examine the fossils found at various depths in some thick stratum, or series of closely related strata, we find that the species change very gradually; but when we pass from one stratum to another of a different kind, above or below it, we often find a considerable difference in the species. The more abrupt the change from one series of strata to another, the greater is the change in the species.

Unconformable stratification is always accompanied by more or less complete change of species.

121. Grouping of Strata According to Age.—Strata mostly occur in groups, the beds making up each group being closely related in lithological[1] characters, and having similar fossils throughout. Such a group of strata is called a *formation*. For instance, in Wales we have a series of dark shales and flagstones, characterised by a fossil shell of the brachiopod class, called *Lingulella*. This series forms one formation, and is known as the *Lingula Flags*. A formation is really a series of deposits which have taken place at a sea-bottom, undisturbed for a long period of time.

Formations, in their turn, occur in natural groups or series, the groups of formations being separated from each other by unusually great changes in the nature of the strata and their included fossils. Thus we have the Silurian formations, the Oolitic formations, etc.

In British strata there is one unusually great break represented by unconformity and great change of species. Advantage is taken of this break, and also of another somewhat less marked, to divide all strata into three great groups, or, rather, to divide time into three great periods. Each of these periods is characterised by the nature of its animal and vegetable life. They are as follows, placing the oldest at the bottom:—

III. Tertiary or Cainozoic (new life).
II. Secondary or Mesozoic (middle life).
I. Primary or Palæozoic (old life).

It will be convenient now to give a list of the principal British formations in their chronological order, the oldest being placed at the bottom.

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[1] Gr. *lithos*, stone.

TABLE OF BRITISH FORMATIONS.

	RECENT.		
	POST-PLIOCENE.		
CAINOZOIC OR TERTIARY.	NEWER PLIOCENE.		
	OLDER PLIOCENE.		
	MIOCENE.		
	EOCENE,		Lower, Middle, and Upper.
MESOZOIC OR SECONDARY.	CRETACEOUS,		Chalk.
			Upper Greensand.
			Gault.
			Lower Greensand.
	WEALDEN,		Wealden.
			Purbeck Beds.
	OOLITE, AND	*Upper,*	Portland Oolite.
			Kimmeridge Clay.
		Middle,	Coral Rag.
			Oxford Clay.
		Lower,	Cornbrash.
			Forest Marble.
			Bath or Great Oolite.
			Stonesfield Slate.
			Inferior Oolite.
	LIAS,		Upper Lias.
			Marlstone.
			Lower Lias.
	TRIAS,		Rhætic Beds.
			Keuper (New Red Marl).
			Bunter(NewRed Sandstone).
PALÆOZOIC OR PRIMARY.	PERMIAN,		Magnesian Limestone.
			Rothliegende.
	CARBONIFEROUS,		Coal Measures.
			Millstone Grit.
			Upper Limestone Shale.
			Carboniferous Limestone.
			Lower Limestone Shale.
	DEVONIAN AND OLD RED SANDSTONE,		Upper.
			Middle.
			Lower.
	SILURIAN,	*Upper,*	Ludlow Group.
			Wenlock Group.
			Upper Llandovery Beds.
		Lower,	Lower Llandovery Beds.
			Bala and Caradoc Beds.
			Llandeilo Beds.
			Tremadoc Slates.
			Lingula Flags.
	CAMBRIAN.		
	LAURENTIAN.		

122. General Structure of Great Britain.—Fortunately for us, Great Britain affords examples of almost all known formations. In this respect we have an advantage over many countries, where thousands of square miles are sometimes occupied by one or two formations. The beginner, therefore, by making short excursions into the country, may observe, with his own eyes, many of the formations mentioned in the table of strata given above.

Before proceeding further, the student should provide himself with a coloured geological map of Great Britain —almost any one will do for general purposes; but he should procure, in addition, the quarter sheet issued by the Geological Survey which embraces his own neighbourhood.

If the student will now examine such a geological map of Great Britain, he will observe that the Mesozoic and Cainozoic rocks occupy the middle, eastern, and south-eastern portions of England, while the older, or Palæozoic rocks occupy Cornwall and Devon, Wales, North of England, and Scotland. The Tertiary rocks, it will be seen, lie principally in two districts, called the London basin, and the Hampshire basin, respectively. When the Tertiary clays and sands of the London basin are penetrated by borings or wells, the *Chalk* is reached, and beyond the limits of the Tertiary strata, the members of the Cretaceous strata come to the surface in succession. Tracing the Cretaceous formations towards the west, we at length find the *Oolite* coming up from under them; the members of the Oolite having, like the Cretaceous strata, a general dip to the east. Passing across the outcrop of the Oolitic series as they come to the surface one after another, we come to the *Lias;* the Oolite, in many places along the boundary, forming an escarpment which overlooks the Lias, plainly showing that at one time the Oolite extended farther to the west than it does now. The Chalk, however, extended even farther than the Oolite; and an isolated patch will be seen on the map, which rests directly on the Trias and Palæozoic rocks in Devonshire. Still farther to the west, we reach the *Trias*, coming up from under the Lias. Proceeding farther, we come upon the Palæozoic rocks, which cover at least two-thirds of the whole island. Being more disturbed than the newer rocks, the Palæozoic strata have not the same uniformity of dip as the former; but still, the general dip is to the east; and we find the lowest members, for the most part, in the extreme west and north,—the oldest known rocks, the *Laurentian*, occurring in the Hebrides and north-western extremity of Scotland.

The Palæozoic strata are usually highly indurated, often metamorphosed, and associated to a great extent with igneous rocks; and having suffered much by denudation on account of their great age, confer upon a great portion of the island a rugged and mountainous character.

We shall now proceed to study the various formations in their chronological order, commencing with the oldest. In the study of rocks, palæontology must necessarily take a prominent position, not only on account of the great importance of fossils in identifying formations, but from the fact that the distribution of life in time is an important study in itself. It is hardly necessary to mention, that in studying the various formations, constant reference should be made to maps, sections, and fossils.

CHAPTER XIV.

PALÆOZOIC FORMATIONS.

123. Antiquity of the Oldest known Rocks.—In beginning our study of geological history with the oldest known rocks, we do not at first acquire so strong an impression of their antiquity as we shall on looking back upon them when we have glanced at the history of the long succession of rocks which followed them.

When, however, we think of the vast number of strata that are proved by superposition to be of different ages, their miles of aggregate thickness, the slowness with which these deposits were made, the many breaks pointed out by intervals, and the vaster ones represented by unconformities, we do form some vague idea of the remote period of time at which we commence our geological history.

Even the oldest known rocks are *stratified*, which points at once to a period still more remote, when other rocks existed, which, by their destruction, furnished the material composing these.

LAURENTIAN SERIES.

124. Laurentian Rocks.—The oldest rocks at present known in the British Isles occur in the outer Hebrides, and in the north-western parts of Sutherland. They are probably of the same age as that of a vast series of rocks occurring in Canada, on the shores of the St Lawrence, from which river the name of the group has been derived.

Both in Canada and Scotland the Laurentian rocks are *overlaid* by strata considered to be of Cambrian age, but no rocks have hitherto been discovered *underlying* them. In this way they are proved to be older than all other known rocks.

The Laurentian rocks of Canada consist of highly metamorphosed sedimentary strata, not less than 30,000 feet (over five miles) in thickness. They are divided into two series by an unconformity, the upper series lying unconformably on the lower. Gneiss is the principal rock; but in the lower series it is interstratified with beds of crystalline limestone.

In Scotland the Laurentian rocks are much contorted, and consist, like the Canadian rocks, of gneiss, with occasional beds of altered limestone.

125. Laurentian Life.—The Laurentian rocks are so old, and so much altered by metamorphic action, that we should scarcely expect to find any trace of animal or vegetable remains in them. But in the limestones of the lower Laurentian rocks of Canada, a fossil occurs named *Eozoon*[1] *Canadense.* It consists of calcareous layers of what was once a series of cells; the cells, formerly occupied by the soft bodies of the animals, being now filled up with calcareous matter. The cells communicated with each other, and were built up layer upon layer, so that large reefs of limestone were formed resembling the reefs built by the coral polyp at the present day. Under the microscope the cell walls of the Eozoon are seen to be pierced by many minute tubes (*tubuli*), which shows it to belong to the group of animals called *foraminifera.*

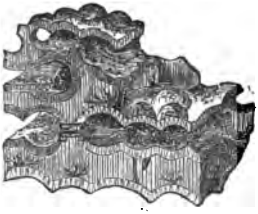

Fig. 28.
Eozoon Canadense (magnified).

Other species of Eozoon have been lately discovered in rocks believed to be Laurentian, in Bavaria, Bohemia, and Finland. No fossil has yet been discovered in the Laurentian rocks of Scotland.

Independently of the existence of the Eozoon, the very beds of limestone themselves indicate the existence of animal life at this period; for we know of none but organic means by which thick and extensive beds of limestone can be formed. Also, occasional layers of graphite[2] are found in the Canadian rocks, which render the presence of plant life probable.

CAMBRIAN SERIES.

126. Cambrian Rocks.—A series of sandstones and slates, older than the Silurian, appear at the surface in several small areas in North Wales. These are called *Cambrian.*[1] They dip below the Silurian to the east, and make their appearance again in the Longmynd, a hilly district in Shropshire, and in a few other isolated patches, one as far to the east as Charnwood Forest in Leicestershire. In the Longmynd the series is over four miles in thickness.

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[1] Gr. *eos,* dawn; *zoon,* animal.

[2] Otherwise known as plumbago and blacklead; really a form of the element carbon.

Cambrian rocks occur also in the English Lake district, in Ireland, Bohemia, and elsewhere.

In the absence of fossils, it is difficult to assign the proper age to strata when the test of superposition fails us. For example, in Canada the Laurentian rocks are covered by a thick series of unfossiliferous slates and quartzites, called the Huronian group; and these, in their turn, are overlaid by Silurian rocks, the latter being easily identified by their fossils. Again, in the north of Scotland the Laurentian gneiss is covered unconformably by a group of strata consisting of red and purple sandstones and conglomerates destitute of fossils; and upon these rest, also unconformably, metamorphosed rocks of Silurian age. We infer at once that the Huronian rocks of Canada, and the group of sandstones and conglomerates of Scotland, are both newer than the Laurentian, and older than the Silurian; but there is nothing to show that they were actually contemporaneous with each other, or with the Cambrian.

The rocks overlying the Laurentian rocks in Scotland are provisionally called Cambrian. The conglomerates of this series are partly made up of pebbles of gneiss, evidently derived from the Laurentian rocks which formed land at the time. More than this, the pebbles inform us that the Laurentian rocks were already metamorphosed into gneiss when the formation of the conglomerates commenced.

Many of the Cambrian sandstones are rain-pitted and ripple-marked, showing them to be shore accumulations. Red and purple sandstones are common; and as later red rocks prove to be for the most part of lacustrine origin, it is not unlikely that many of the Cambrian strata were deposited in large lakes, possibly fresh-water.

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[1] From *Cambria,* the ancient name of Wales.

The Cambrian slates of North Wales are quarried to a large extent. The largest slate quarries in the world lie in the Cambrian rocks of Carnarvonshire.

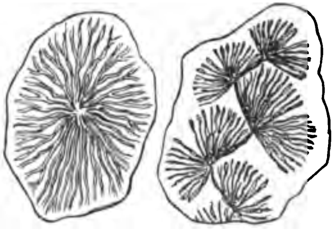

Fig. 29.—Oldhamia radiata; O. antiqua.

127. Cambrian Fossils.—The fossils hitherto furnished by Cambrian strata are scanty and of few species. At Bray Head in Ireland, two species, probably belonging to the polyzoa, have been found, and named *Oldhamia radiata* and *O. antiqua* respectively.

Worm tracts and burrows have been found in the Longmynd. More lately, the Cambrian beds in the neighbourhood of St Davids, Pembrokeshire, have yielded, besides lower forms, brachiopods, pteropods, and trilobites, some of the latter of very large size.

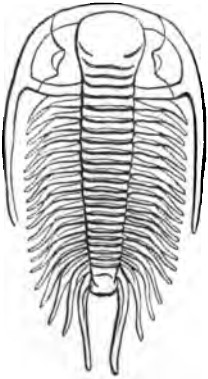

Fig. 30.
Cambrian trilobite
(Paradoxides Davidis),
1-10th natural size.

The *trilobite* was a crustacean, and the order to which it belongs particularly characterises the Palæozoic rocks from the Cambrian to the Devonian. It derives its name from the three longitudinal lobes into which its body was divided. It was protected on the back by a crustaceous covering consisting of a plate shielding the head, below which were a series of segments jointed together, and terminated by a tail-plate. These hard coverings are the only parts found fossil. Little or nothing is known of the covering and appendages of the ventral portion of the animal.

SILURIAN FORMATIONS.

128. Silurian Rocks.—The Cambrian rocks in Wales pass upwards without any apparent break into the lowest of a series of rocks called *Silurian.*[1] These cover a large portion of Wales, and extend into the neighbouring counties of England.

An unconformity separates the series into two groups—lower and upper. The former are mainly exposed in the west, and the latter in the east of the district above mentioned.

The following is the succession of the Silurian formations in Wales and adjoining counties of England :—

			Feet.
Upper,	Ludlow Group,	Tilestones,	1000
		Upper Ludlow,	900
		Aymestry Limestone,	150
		Lower Ludlow,	900
	Wenlock Group,	Wenlock Limestone,	150
		Wenlock Shale,	1400
		Woolhope Limestone,	50
		Tarannon Shale,	600
	Upper Llandovery Beds,		900
Lower,	Lower Llandovery Beds,		1000
	Bala and Caradoc Beds,		6000
	Llandeilo Beds,		5000
	Tremadoc Slates,		1000
	Lingula Flags,		5000

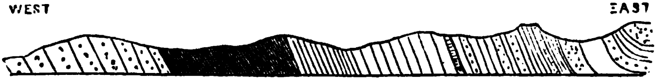

Fig. 31.—Section across the country south of Lake Bala.

Lingula Flags.—This is a series of dark shales and flagstones which conformably succeed the Cambrian rocks in Wales. They owe their name to a fossil they contain called *Lingulella* (formerly called *Lingula*).

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[1] From the *Silures*, a tribe of ancient Britons who inhabited part of South Wales.

Tremadoc Slates.—This is a local formation, occurring only in the neighbourhood of Tremadoc in Carnarvonshire.

Llandeilo Beds.—These consist mainly of dark slates and sandy flagstones, with occasional beds of sandstone. They are exposed in the neighbourhood of Llandeilo, also in North Wales.

Bala Beds.—A group of strata developed in the neighbourhood of Lake Bala, consisting chiefly of slates, shales, and grits, with two beds of limestone. (Fig. 31.)

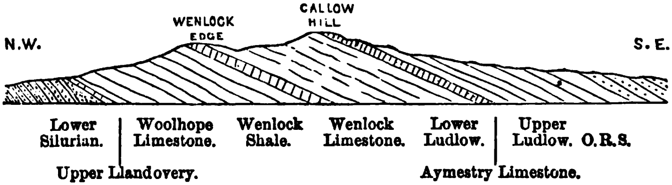

Fig. 32.—Section across Wenlock Edge.

Llandovery Beds.—These are often denominated the *passage beds*, connecting, as they do, but with missing links, the Lower and Upper Silurian series. They are well exposed in the neighbourhood of Llandovery in Carmarthenshire. The lower beds consist of conglomerates, sandstone, and shales, and upon these lie *unconformably*, the conglomerates and sandstones of the Upper Llandovery formation. It is this unconformity which separates the upper from the lower Silurian. These beds are also known as the *Pentamerus Beds*, from the large numbers of a fossil brachiopod of this name found in them.

Wenlock Group.—This group consists mainly of limestone and shales. It is well exposed in several parts of Herefordshire and neighbouring counties; for example, at Wenlock Edge (Fig. 32), Woolhope Valley, and the west flanks of the Malvern Hills.

Ludlow Group.—This group also consists of limestones and shales, and is developed, among other places, about Ludlow in Shropshire.

Silurian rocks also occur in the Lake district (Cumberland and Westmoreland). The formations in this district usually differ in lithological characters from those in Wales, but the *geological horizons* represented by the formations in Wales have been traced in them, principally by aid of the fossils they contain.

The Highlands of Scotland mainly consist of lower Silurian rocks. These lie unconformably on the Cambrian, and are much crumpled and metamorphosed, being changed into quartzites, gneiss, and schists, and associated with great bosses of granite and syenite. There are also some beds of altered limestone which have yielded a few fossils, and it is by means of these fossils that the series are recognised as Silurian.

Interbedded with the Llandeilo and Bala Beds in North Wales, are many volcanic lavas and ashes, indicating the action of marine volcanoes in these times. Snowdon exhibits many beds of this description, some of which are of great thickness.

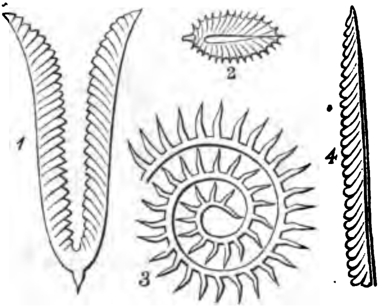

Fig. 33.—*Graptolites.*

129. Silurian Fossils.—Silurian rocks, especially the upper ones, abound with fossils belonging to many different classes, from fishes downwards, and with one exception (a land plant) they are all marine forms.

Land Plants are represented in the Upper Ludlow

Beds by the spore cases and fragments of a cryptogamic plant. This is the first appearance of land plants.

Graptolites (pen-stones, Fig. 33) are very characteristic, being only known in Silurian rocks. They first appear in the Tremadoc Slates, become abundant in the Llandeilo and Bala Beds, are scanty in the Upper Silurian, and disappear before its close.

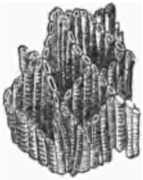

Fig. 34.—*Halysites catenularius*. Upper and Lower Silurian.

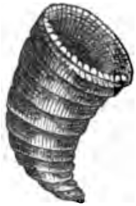

Fig. 35.—*Omphyma turbinatum*. Wenlock.

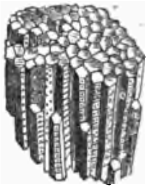

Fig. 36.—*Favosites Gothlandica*. Bala to Ludlow.

Corals are abundant, such as *Omphyma*, *Favosites*, and *Halysites* (chain coral).

Brachiopoda are very common. *Lingulella Davisii* occurs in the Lingula Flags. The genus to which it belongs closely resembles the living genus *Lingula*. The genera *Orthis*, *Spirifera*, *Rhynconella*, *Pentamerus*, and *Atrypa*, occur plentifully.

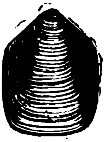

Fig. 37.—*Lingulella Davisii*. Lingula Flags.

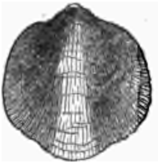

Fig. 38.—*Atrypa reticularis*. Llandovery to Ludlow.

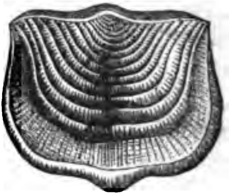

Fig. 39.—*Strophomena depressa*. Wenlock and Ludlow.

Lamellibranchiata (ordinary bivalves) are represented, but the number of species is far exceeded by the brachiopod bivalves.

Gasteropoda.—*Murchisonia* and *Euomphalus* are abundant.

Pteropoda.—The genera *Theca* and *Bellerophon* are examples.

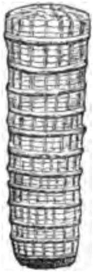

Fig. 40.—*Orthoceras annulatum*. Bala to Wenlock.

Cephalopoda.—This class makes its first appearance in the Tremadoc Slates. *Orthoceras* (straight horn) is the most important genus.

Echinodermata are represented by *Palæaster* (a star-fish) and *Pseudocrinus* (an encrinite).

Crustacea.—*Trilobites* are very abundant; many genera and species occur. Figures of *Trinucleus*, *Phacops*, and *Calymene*, are given; these are well known, as are also *Olenus*, *Ogygia*, *Asaphus*, *Illænus*, *Ampyx*, and *Homalonotus*. Some of the trilobites seem to have had the power of rolling themselves into a ball, as the woodlouse does; the *Calymene* is often found in this condition. The Lingula Flags yield a shrimp-like crustacean called *Hymenocaris*.

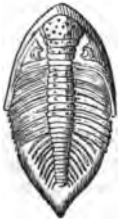

Fig. 41.—*Phacops caudatus*. Upper Silurian.

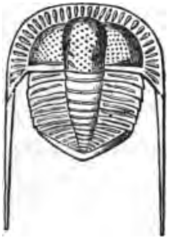

Fig. 42.—*Trinucleus fimbriatus*. Llandeilo.

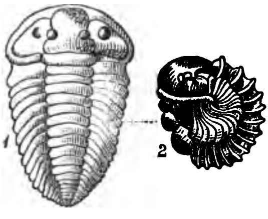

Fig. 43.—*Calymene Blumenbachii*. Bala to Ludlow.

Fish Remains.—Teeth and fragments of bone are common in a stratum at the top of the Upper Ludlow known as the "*Bone Bed.*" A fossil fish has even been found in the Lower Ludlow, and is the oldest known vertebrate.

OLD RED SANDSTONE AND DEVONIAN FORMATIONS.

130. Old Red Sandstone Rocks.—In the district about Herefordshire and Shropshire, the uppermost beds of the Silurian series pass insensibly into a group of red sandstones, flagstones, conglomerates, etc., known as the *Old Red Sandstone.* Similar rocks occur in Scotland and Ireland. The prevailing rock is sandstone, coloured with red oxide of iron; hence the name "Red Sandstone." It is further called "Old," to distinguish it from the *New Red Sandstone,* a formation of the Trias.

In Scotland two distinct unconformities separate the Old Red Sandstone into three series, called Lower, Middle, and Upper. These unconformities have not been observed in the Herefordshire district, but still they may exist, for the whole of the series is not exposed. Parts of the Old Red Sandstone often lie unconformably on both Upper and Lower Silurian Rocks.

In the Herefordshire district the Old Red Sandstone is 8000 or 10,000 feet in thickness, but in Scotland it does not reach more than half this thickness.

131. Old Red Sandstone Fossils.—Where the Upper Silurian passes into the Old Red Sandstone, as in Herefordshire and Staffordshire, the Silurian species present in the "Passage Beds" gradually become dwarfed and few in number, and soon disappear, being replaced by others, chiefly remains of fishes, crustaceans, and plants; but none of these are at all plentiful. Marine shells and corals are entirely absent.

LAND PLANTS.—Fragments are frequently found in the upper beds of the Herefordshire district, Ireland, and elsewhere. They consist of club-mosses, tree-ferns, Lepidodendron, etc.

SHELLS.—No shells are found in the Old Red Sandstone of Great Britain. In the upper beds in Ireland a bivalve shell is abundant, resembling the fresh-water mussel of English rivers (*Anodon*); it is called *Anodonta.*

CRUSTACEA.—Remains of large crustaceans are found in Forfarshire, to which the name *Pterygotus* is given. The quarrymen call them seraphims. These creatures had elongated bodies like the lobster, and were often 5 or 6 feet in length. Among the remains of numerous grass-like plants found in these rocks, occur groups of semi-globular bodies, called berries by the quarrymen. They resemble the eggs of crustaceans; and as they are sometimes accompanied by the remains of the Pterygotus, it is highly probable they are the egg packets of that crustacean.

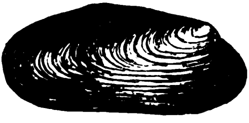

Fig. 44.—*Anodonta Jukesii.* Upper Old Red Sandstone, Ireland.

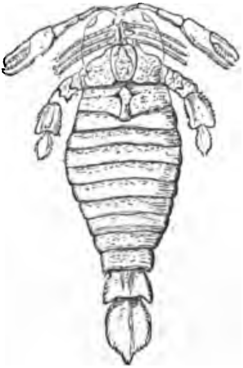

Fig. 45.—*Pterygotus anglicus* (restored). Forfarshire.

FISHES.—The Old Red Sandstone is remarkable for its fish remains, which are so numerous that the period has been styled the "Age of Fishes." Fish remains are especially abundant in the Old Red Sandstone of Scotland. The fishes were mostly of the *ganoid*[1] type, being covered with bony and enamelled plates, like the sturgeon now living. Some were *placoid*,[2] the skin being dotted with numerous small plates or points of hard bony matter, like the shark. In no case was the skeleton perfectly hardened, and their tails were all unequally lobed. Among the most remarkable of these fishes are *Asterolepis*, a huge fish, often attaining a length of between 20 and 30 feet; *Holoptychius*, also a large fish, and having peculiar wrinkle-like marks on its scales; *Pterichthys*, covered with large bony plates, while its single pair of fins takes the form of paddles, and being

[1] Gr. *ganos*, brightness.

[2] Gr. *plax*, a flat plate.

placed near the head, looks like a pair of wings; *Cephalaspis*, remarkable for the peculiar shield-like plates about its head; *Osteolepis*, *Coccosteus*, and *Dipterus* may also be mentioned.

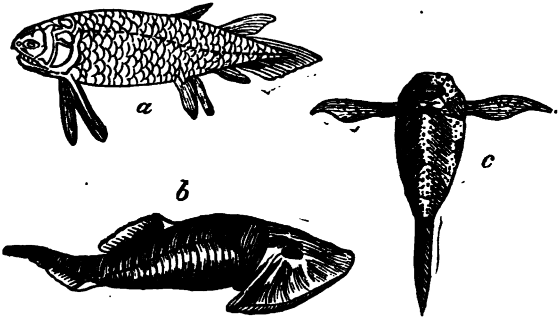

Fig. 46.—Group of Old Red Sandstone Fishes.
a Holoptychius. *b Cephalaspis.* *c Pterichthys.*

132. Conditions under which the Old Red Sandstone was Deposited.—The Old Red Sandstone appears to have been deposited in great inland lakes, probably salt at first, but at length decidedly fresh-water. We are led to this conclusion by the following considerations. The change of species accompanying the gradual passage of the Upper Silurian into the Old Red Sandstone implies a change of conditions, the new conditions having been unfavourable to ordinary marine life, as no marine shells or corals occur, and calcareous beds are altogether absent; the land plants indicate the nearness of land; and the fishes, the genera of which have long been extinct, have their nearest representatives living in African rivers, and in lakes and rivers of North America.

It would seem that during the later part of the Silurian period, the neighbourhood of the British Isles, at least, was slowly rising, and at length the Silurian districts in Wales, Cumberland, and Scotland became land, enclosing a series of extensive lakes, in which the Old Red Sandstone was deposited, the material being derived from the waste of the surrounding Silurian and older rocks; the red oxide of iron, which is so prevalent in this formation as a colouring and cementing material, having been probably derived from the waste of igneous or metamorphic rocks.

The base of the Old Red Sandstone in Scotland consists of conglomerates, among which are many huge masses, so large as to render it scarcely possible that water could have carried them to the place where they are found. Moving ice seems to be the only agency capable of transporting and accumulating blocks of so great a size. Hence these coarse conglomerates of Scotland point to a cold climate at this period, when glaciers ploughed their way down the valleys of the early Scottish mountains, and deposited their moraine rubbish in the Old Red Sandstone lakes.

133. Devonian Rocks.—In Devon and Cornwall a series of calcareous and slaty strata overlie the Silurian Rocks, and are in their turn overlaid by strata of the Carboniferous age. This formation is termed Devonian; it is probably contemporaneous with the Old Red Sandstone.

The Devonian Rocks are all much disturbed, contorted, and intermingled with igneous rocks. They are usually divided into three groups, Lower, Middle, and Upper.

The term Devonian is sometimes applied to the whole period intermediate between the Silurian and Carboniferous, and including the Old Red Sandstone. Rocks of this age are extensively distributed throughout the world. In the United States, Devonian Rocks cover an area nearly as large as Europe.

134. Devonian Fossils.—The Devonian Rocks abound with corals, marine bivalve and univalve shells, trilobites, etc.; and in this respect contrast strongly with the Old Red Sandstone. The nature of the Devonian fossils places its marine origin beyond a doubt; hence, if this formation is contemporaneous with the Old Red Sandstone, it gives us a clue to the marine conditions coincident with the continental state of things represented in a fragmentary manner by the "Old Red" deposits.

Plants are represented by similar species to those of the Old Red Sandstone. In North America, plants are very abundant, and resemble for the most part those of the Carboniferous series lying above.

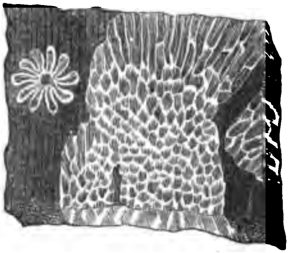

Fig. 47.
Favosites cervicornis.
S. Devon.

Corals are very abundant. *Cyathophyllum*, *Favosites*, *Spongites*, and *Heliolites*, are examples.

Shells.—Among the brachiopods, the genera *Spirifer*, *Stringocephalus*, and *Atrypa* are common. The conchifer *Megalodon* is characteristic. Gasteropods are represented by *Euomphalus* and *Murchisonia*. The cephalopods *Clymenia* and *Goniatites* occur in the upper beds.

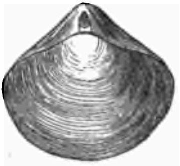

Fig. 48.
Stringocephalus Burtini.
Middle Devonian.

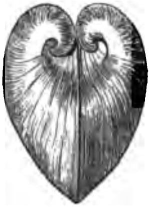

Fig. 49.
Megalodon cucullatus.

Crustacea.—Trilobites are represented by *Brontes*, *Phacops*, *Homalonotus*, and other genera.

Insects.—Several species allied to the dragon-fly have lately been found in the Devonian Rocks of Canada. These are the oldest known insects.

Vertebrates.—Fish remains occur, but are rare in the Devonian rocks of England.

CARBONIFEROUS FORMATIONS.

135. Carboniferous Rocks.—In South Wales the Old Red Sandstone is conformably succeeded by a series of black shales, which form the base of the group of formations called *Carboniferous.* This name has been given to the group on account of the remarkable prevalence in it of beds of coal. In several places Carboniferous Rocks are found lying directly and unconformably upon Silurian, and even Cambrian Rocks.

The following are the principal members of the Carboniferous series, as exhibited in Wales and the south of England:—

$$\text{Coal Measures, }\left\}\begin{array}{l}\text{Upper.}\\ \text{Middle.}\\ \text{Lower.}\end{array}\right.$$

Millstone Grit.
Upper Limestone Shale.
Carboniferous Limestone.
Lower Limestone Shale.

The *Carboniferous Limestone* in Derbyshire, Wales, and south of England, consists chiefly of beds of semicrystalline limestone. Being much carved by denudation in many places, it gives a mountainous character to the districts; hence the name "Mountain Limestone," by which it is often known.

The *Millstone Grit* is a coarse sandstone, often passing into a conglomerate, and associated with beds of shale. The name is derived from the use to which some of the finer gritstones are applied. In the South Wales district the Millstone Grit is called by the miners the "Farewell Rock," no beds of coal occurring below it. In Scotland it is represented by the "Moor Rock."

The Millstone Grit, together with the Carboniferous Limestone, and Upper Limestone Shale, or their equivalents, form a wide mountainous band stretching from Derbyshire to the Cheviot Hills.

In Derbyshire the Carboniferous Rocks form a broad anticlinal curve, the axis of which runs north and south. The Carboniferous Limestone, the lowest of the series which is exposed, occupies the highest portion of the curve, and is flanked on the east and west by the Upper Limestone Shale (Yoredale Rocks, etc.), and these in their turn are covered by the Millstone Grit, which presents long escarpments to the axis of the curve. Resting upon the Millstone Grit on either side of the district, are the Coal Measures; those to the east forming the great Derbyshire and Yorkshire coal-field; those to the west, the North Stafford and Lancashire coal-fields.

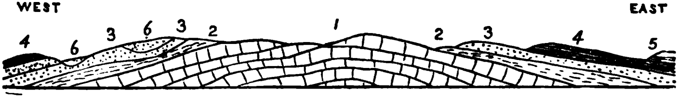

Fig. 50.—Section across the Carboniferous Limestone of Derbyshire.

1. Carboniferous Limestone.
2. Upper Limestone Shale.
3. Millstone Grit.
4. Coal Measures.
5. Permian.
6. Trias.

Lodes rich in galena (sulphide of lead) are numerous in the Carboniferous Limestone of North Wales, Derbyshire, and other places.

136. Coal-Beds.—Although coal itself is not necessarily of any particular geological age, yet the Carboniferous Rocks of Europe and North America contain far more coal than all the other formations put together. In the southern coal-fields of Great Britain the coal-beds are confined to the *Coal Measures* lying above the Millstone Grit; but in the north of England, rocks equivalent to the Millstone Grit contain coal, and many of the Scottish coal-beds are of still older date. The principal coal-fields of Great Britain lie in South Wales and the adjoining English counties, in the central and northern counties of England, and in the south of Scotland. It is probable that the greater number of the British coal-fields originally formed one continuous bed, but have since been separated by contortion of the strata and subsequent denudation. This is very evident in the case of the South Wales and Forest of Dean coal-fields.

Coal-beds, like parts of many other formations, often occur in basins (108); not that they were originally deposited in basins, but having suffered disturbance whereby they were bent into curves, and being comparatively soft and easily wasted, they have been removed by denudation in those places where they formed anticlinal curves; while in those districts where the strata became depressed into basins, they have been protected from the action of denuding agents, and so preserved.

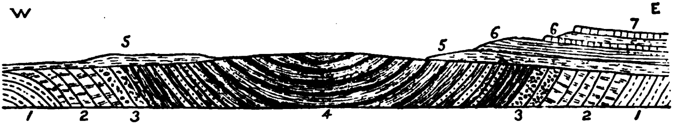

Fig. 51.—Section through the Bristol Coal-field.

1. Old Red Sandstone.
2. Carboniferous Limestone.
3. Millstone Grit.
4. Coal Measures.
5. Trias.
6. Lias.
7. Lower Oolite.

In Ireland the Carboniferous strata have not been much disturbed, and the consequence is, that although the Carboniferous Limestone is largely developed, there is very little coal, except in a few places where the strata have been bent into basins.

In sinking shafts through the coal measures in the search for coal, many seams are usually passed through, interstratified with beds of shale, sandstone, and ironstone. Coal seams vary in thickness from a few inches to many feet. In the South Wales coal-field no fewer than eighty coal seams are passed through, having an aggregate thickness of not more than 120 feet.

137. Volcanic Rocks of Carboniferous Age.—English Carboniferous Rocks are often greatly bent and much faulted, but volcanic rocks are quite unknown, except in the case of the Carboniferous Limestone of Derbyshire, which has intercalated with it three thick beds of a kind of greenstone locally called "toadstone," often associated with clays which have resulted from the decomposition of the volcanic ash which accompanied the outpouring of the lava. (See 43.) In the Carboniferous Rocks of Scotland beds of lava and volcanic ashes are very numerous.

138. Carboniferous Limestone Fossils.—CORALS such as *Syringopora*, *Lithostrotion*, *Amplexus*, etc., are common.

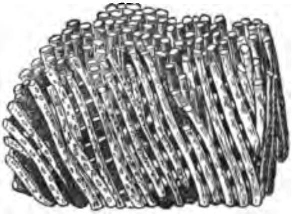

Fig. 52.—*Syringopora ramulosa.*

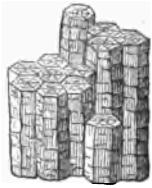

Fig. 53.—*Lithostrotion basaltiforme.*

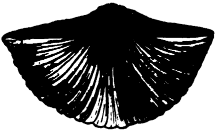

Fig. 54.—*Spirifera striatus.*

SHELLS.—Among the brachiopods the genus *Spirifera* is common; it is so called from the pair of internal spiral processes the shells contain. *Productus* is also common. *Terebratula hastata* is characteristic; so is the gasteropod *Euomphalus pentangulatus.* Among the cephalopods, the genera *Goniatites* and *Nautilus*, first met with in the Upper Devonian, are found here; so also is the *Orthoceras.* The genera *Goniatites* and *Orthoceras* become extinct shortly after the Carboni-

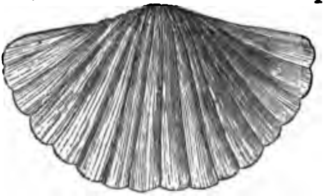

Fig. 55.—*Productus giganteus.*

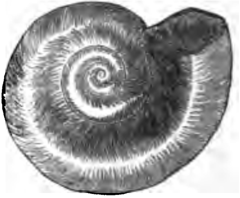

Fig. 56.—*Euomphalus pentangulatus.*

ferous period, but the *Nautilus* persists to the present day.

Echinodermata.—Crinoids, or sea-lilies (82), especially characterise these rocks. Pentremites, Actinocrinus, and Cyathocrinus are characteristic genera. Some of the limestones of Derbyshire consist almost entirely of encrinital stems.

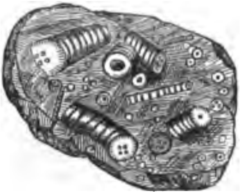

Fig. 57.—Weathered Encrinital Limestone.

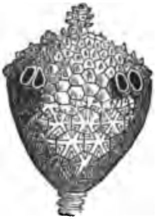

Fig. 58.—*Actinocrinus.*

Crustacea.—Among other crustacea, the trilobites are still represented; but this is their last appearance. *Phillipsia* and one or two others occur; they are, however, of small size and rare.

Fishes.—Some of the Old Red Sandstone genera occur; among them *Holoptychius*, together with new genera, as *Megalichthys*, *Psammodus*, *Cladodus*, etc.

139. Fossils of the Coal Measures.—The coal itself has undergone so complete a change that it does not usually exhibit a vegetable structure. In the shales, however, which accompany beds of coal, carbonised fern leaves and other parts of plants are numerous.

Plants.—The fronds of tree-ferns are numerous in the shales. *Pecopteris* and *Neuropteris* are figured; besides these, there are *Sphenopteris*, *Cyclopteris*, and many others. The stems of huge reed-like plants allied to the horse-tails, named *Calamites*, are very common.

The bark and stems of a large tree named *Sigillaria* are abundant. The bark is marked by a series of impressions differing in pattern with different species. The roots of this tree are found in a separate stratum underneath the coal. They were long thought to be the stems of another plant, and still go by the distinct name *Stigmaria ficoides.* The nearest representative of this large tree is the little club-moss of the present time. The *Lepidodendron* is another large tree, with a peculiar scale-like bark, and still more closely allied to the club-moss. The leaves of this tree have been found attached to the stem, and its fructification, consisting of cones made up of spore cases, is frequently found, and has received the name *Lepidostrobus.* The higher orders of

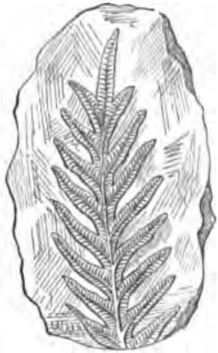
Fig. 59.—*Pecopteris.*

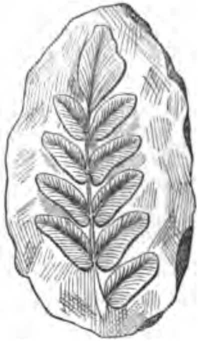
Fig. 60.—*Neuropteris.*

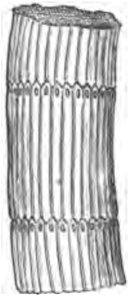
Fig. 61.—*Calamites.*

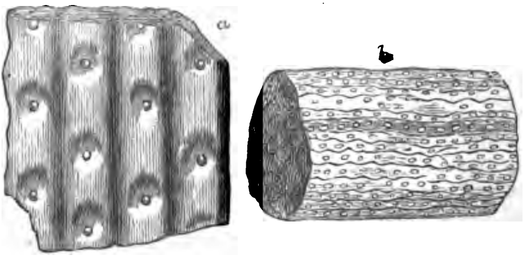

Fig. 62.—*Sigillaria.* *a* bark with pittings; *b* root (*Stigmaria ficoides*).

plants are represented by coniferous trees allied to the pine.

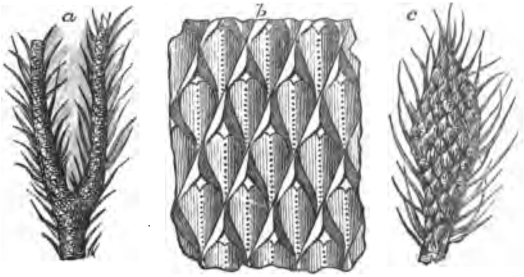

Fig. 63.—*Lepidodendron.* *a* small branch; *b* bark with scale-like markings spirally arranged; *c* fructification (*Lepidostrobus*).

SHELLS.—*Goniatites* and *Aviculo-pecten,* both marine. *Anthracosia* (allied to the Unio), probably fresh-water. *Land shells* occur in the coal measures of Nova Scotia.

INSECTS.—European and North American coal-beds yield white ants, grasshoppers, cockroaches, and others.

REPTILES.—Remains of *Archegosaurus* and other large amphibians occur in European coal-beds. In North America many species of reptiles have been found.

140. Conditions under which the Carboniferous Rocks were Accumulated.—After the deposition of the Old Red Sandstone in the British area, the land must have slowly subsided, the Lower Limestone Shale marking the transition from fresh to brackish-water. As the sea deepened, and marine conditions set in, the deposition of the Carboniferous Limestone took place; its corals, encrinites, and sea-shells establishing its marine origin. In the North of England and Scotland considerable oscillations of level evidently occurred at this period, for the group of beds below the Millstone Grit contains several fresh-water and terrestrial (coal) beds. After the deposition of the Millstone Grit in the British area, a general emergence of the land and shallowing of adjacent seas took place, followed by the accumulation of the Coal Measures,

BIBLIOTHECA BODLEIANA

consisting of an alternation of terrestrial, fresh-water, and marine beds.

141. Formation of Beds of Coal.—The vegetable origin of coal having been demonstrated (84), we may now endeavour to ascertain by what means extensive beds of vegetable matter were accumulated, and subsequently converted into coal; also, how it happens that many beds of coal occur in one series with interbedded shales, sandstones, and ironstones.

The quantity of coal belonging to this period indicates a remarkable profusion of vegetable growth. Fossils show this vegetation to be terrestrial, and to consist chiefly of cryptogamic plants. The character of the plants point to a climate, not necessarily tropical, but warm, moist, and free from extremes.

The freedom of coal-beds from the detritus of the land, the upright stumps of trees found in them, also the insects and land-shells, suggest that the vegetable matter which afterwards formed the coal accumulated on the spot where it had grown, and this is put beyond all doubt by the existence under almost every bed of coal of a stratum of clay, or some such material, known as the *underclay*, and which is full of stigmaria, and other roots of plants, to the exclusion of other forms of fossils. The underclay undoubtedly represents the original soil upon which the plants now forming the coal-beds grew.

The extent of many coal-beds shows the original forests, jungles, or peat-mosses, which gave rise to the coal, to have been of great magnitude; and the thickness of many beds shows the growth to have been undisturbed for long periods of time, until a considerable amount of peaty matter had accumulated beneath the forests and jungles. In some cases whole forests are found compressed into strata but a few inches in thickness.

The stratum which covers each bed of coal is usually fresh-water, indicating that the vegetable matter was accumulated on low-lying ground, near the estuary of a river, which ground being subsequently depressed, became part of the estuary, and received fresh-water deposits. Sometimes marine deposits rest immediately upon the coal, but in either case it is clear that subsidence of the peat beds, or other vegetable matter, took place. A pile of coal-beds, interstratified with clays, shales, sandstones, etc., implies that the district was frequently above or near the surface of the water, and as frequently depressed below it. For such a series to be formed, it is not necessary that there should be any actual upheaval; the only essential condition being a gentle subsidence, with periods of repose, during which the shallow waters of the estuary would become sufficiently silted up for vegetable matter to resume its growth. An alternation of delta deposits, vegetable growth, and submergence, would in time give rise to a series consisting of numerous beds of coal interstratified with shales, sandstones, and ironstones, as we find them in our coal-fields.

PERMIAN FORMATIONS.

142. Permian Rocks.—The Carboniferous series in England is succeeded unconformably by a group of strata called Permian,[1] which lie in hollows produced by denudation in the older rocks. The older members of this series occur in many small areas in the south of Scotland, Cumberland, and Lancashire, and border many of the coal-fields in North Wales and districts to the south of this. The upper member of the series—the Magnesian Limestone—is chiefly exposed in a long narrow band which borders the east side of the great Derbyshire and Yorkshire coal-fields, and extending to Northumberland, skirts the east side of the coal-field there. All along this line the Magnesian Limestone presents a scarped edge to the west. Permian rocks are well developed in Germany.

The following is the succession of the Permian series in England and Germany:—

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[1] From Perm, a Russian province, where rocks of this age occupy an area twice the size of France.

England.	*Germany.*
Red Gypseous Marls. Magnesian Limestone.	Zechstein (mine stone).
Marl Slate.	Kupfer Schiefer (copper slates).
Lower Red Sandstone, or Rothliegende.	Rothliegende (red layers).

The *Rothliegende* consists of red sandstones, marls, and brecciated conglomerates. The *Marl Slate* is a band of marls and calcareous shales. Magnesian limestones are prevalent above the Marl Slate, but not exclusively so, nor are magnesian limestones peculiar to this formation, occurring, as they do, in the Carboniferous and other formations.

143. Permian Fossils.—The fossils of this formation are in general very scanty. The unconformity of the Permian strata on the Carboniferous is associated, as we might expect, with a considerable change of species. Many of the Carboniferous genera of plants appear, but they are all of new species. Among the Palæozoic fauna—*Pentamerus*, *Strophomena*, *Euomphalus*, *Goniatites*, *Orthoceras*, *Cephalaspis*, and many others, which existed up to this time, now finally disappear as far as British strata are concerned. Notwithstanding this great change, the fauna and flora are much more closely allied to those of the Carboniferous Rocks than to those of the Mesozoic formations above.

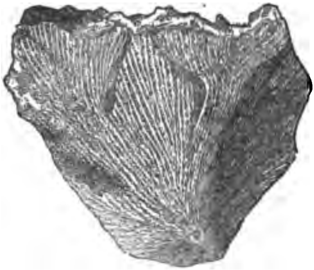

Fig. 64.—*Fenestella retiformis.*
Magnesian Limestone.

POLYZOA.—Among these the *Fenestella* is characteristic.

BRACHIOPODA are represented by *Productus horridus*, *Spirifera alata*, and others.

CONCHIFERA.—*Schizodus*, *Bakevellia*, *Pecten*, etc.

FISHES.—The Marl Slate abounds with fish remains.

Among these are *Palæoniscus, Platysomus, Cœlacanthus,* etc.

Reptiles.—Footprints occur in the Rothliegende, near Dumfries; bones of lizards in the slate, near Durham, and other places.

144. Conditions under which the Permian Strata were Deposited.—Before the deposition of the Permian strata, the British and a much wider area, seems to have become a continental surface, and to have undergone considerable denudation, resulting in some districts in the formation of deep depressions, which subsequently became salt lakes, and in which the Permian strata were deposited. Both in the red rocks, which resemble the Old Red Sandstone, and in the Magnesian Limestone, the fossil species are dwarfed and scanty, in this respect resembling the fauna of the Caspian Sea at the present time. Land-plants, amphibian remains, and footprints, show the proximity of land. The molluscs, though salt-water species, are not necessarily oceanic.

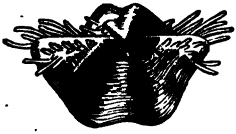

Fig. 65.—*Productus horridus.*
Magnesian Limestone.

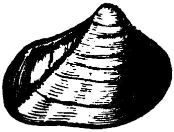

Fig. 66.—*Schizodus.*
Magnesian Limestone.

The Magnesian Limestone appears to have been deposited in a distinct hollow from those in which the deposits of the other Permian districts were made. Beds of gypsum are common in its interstratified marls, giving additional evidence of its lacustrine origin. The presence of carbonate of magnesia with the carbonate of lime can be accounted for by supposing the two to have been precipitated together in consequence of evaporation in a lake saturated with them. The structure of this formation in many places is such as to render it very improbable that it is an ordinary organically formed limestone.

In Cumberland, South Staffordshire, and other Permian districts, evidence is afforded of a *glacial period* having occurred at the commencement of this epoch, similar to that which has already been referred to in the case of the Old Red Sandstone (132). The *Brecciated Conglomerates* of these districts contain many huge blocks, together with smaller stones, all more or less angular, and scratched and furrowed like the moraine stones of a glacier. They cannot therefore be water-borne. These conglomerates are usually imbedded in a red marly paste, and altogether resemble, more than anything else, the boulders and finer detritus accumulated by glaciers and melting icebergs. The blocks have chiefly been brought from Wales, the glacier-covered mountains of which must have been very much higher than they are now, seeing the vast amount of denudation to which they have since been subjected.

145. General Nature of Palæozoic Rocks and Fossils.—These rocks, on account of their great relative age, have been more subject to disturbance than any others, consequently we find they are often bent and contorted, faulted, metamorphosed, and associated with volcanic effusions.

The life of the period is remarkable as being confined to the lower classes of animals generally. Cryptogamic plants, corals, brachiopods, crustaceans, echinoderms, and fishes are the most characteristic. The corals were four-rayed, and the fishes had heterocercal tails, like those of the shark and a few other fishes living now. The ordinary bivalves were much behind the brachiopods in point of number and importance, but began to be in the ascendancy about the close of the period. No traces of mammals or birds have yet been discovered in these rocks.

CHAPTER XV.

MESOZOIC PERIOD.

MESOZOIC LIFE.—The unconformability of the Mesozoic on the Palæozoic rocks is accompanied by great changes in the nature of the fossils. The majority of the Palæozoic genera are lost sight of, while many new genera successively appear. Fishes with homocercal tails now occur, as do also six-rayed corals; conchifera outnumber the brachiopods, and gradually increase their ascendancy until the present day; reptiles become abundant; and warm-blooded vertebrates—mammals and birds—are present.

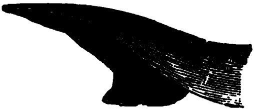
Fig. 67.—Heterocercal tail, like that of the shark.

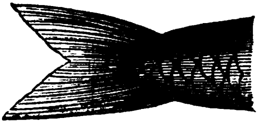
Fig. 68.—Homocercal tail, like that of the herring.

TRIASSIC FORMATIONS.

146. Triassic Rocks.—Upon the disturbed and denuded Palæozoic rocks of England, an extensive series of sandstones, marls, and other strata, lie in nearly horizontal beds. This series is called the *Trias*, from its threefold division in Germany: the middle division, however, is absent with us.

The Trias is extensively developed in England. The greater part of it forms one connected mass, occupying the central counties, and sending an arm along the valley of the Severn, which then in disconnected patches extends southwards to the mouth of the Exe in Devonshire. North of the town of Derby the great Carboniferous anticlinal separates the Trias into two bands, which trend northwards, on the west side beyond the mouth of the Ribble, and on the east as far as the mouth of the Tees. The Trias is absent or only slightly developed in Scotland.

Divisions :—

England.	*Germany.*
2. New Red Marl.	3. Keuper (copper).
———	2. Muschelkalk (shell limestone).
1. New Red Sandstone.	1. Bunter-Sandstein. (variegated sandstone).

New Red Sandstone, or Bunter, consists of soft, red, and mottled sandstones, with beds of uncompacted pebbles. It thins away to the south-east, and at length disappears, the Keuper resting directly on Carboniferous or Permian formations. Thickness 700 to 1000 feet.

Muschelkalk.—Limestones, well developed in Germany, and full of fossils. No representative in England.

New Red Marl or Keuper.—Consists at the base of compact sandstones holding back water, called *waterstones*. These are often ripple-marked and impressed with footprints. The *waterstones* are covered by a series of beds of marl, interstratified with beds of rock-salt and gypsum. The average thickness of the Keuper is about 1200 feet, but is much greater in Cheshire. Where the Keuper rests on the Bunter, it usually does so with a slight unconformity.

At the base of the Keuper near Bristol is a remarkable dolomitic conglomerate containing bones of reptiles.

The Keuper marls are remarkable for their beds of rock-salt. These are chiefly worked in Cheshire, where the series has great thickness. At Droitwich, in Worcestershire, the salt is obtained from brine pumped from these beds. Beds of salt and gypsum are very general in the same geological horizon.

The unconformability of the Trias on the Palæozoic rocks renders the sinking through it for coal a very uncertain operation. Before this is attempted it is necessary to make a careful study of the *lie* of the rocks in the district.

147. Triassic Fossils.—The Triassic strata of England are rarely fossiliferous: land plants, small bivalve crustaceans, fishes, and footprints of amphibians are of occasional occurrence. It is chiefly to the Muschelkalk we have to look for the representative species of the age.

PLANTS.—Silicified trunks of coniferous trees, etc., in England. *Equisetites*, and others, in Germany.

SHELLS.—Many species in the Muschelkalk. The cephalopod *Ceratites nodosus* is characteristic.

ECHINODERMATA.—*Encrinites liliformis*, and others, in the Muschelkalk.

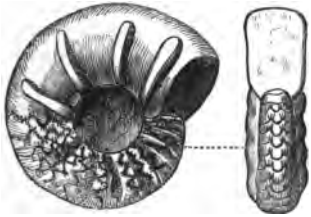

Fig. 69.—*Ceratites nodosus.*
Muschelkalk.

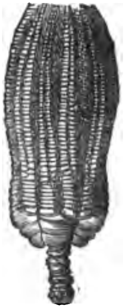

Fig. 70.—*Encrinus liliformis.*
Muschelkalk.

CRUSTACEA.—A small crustacean, with a kind of bivalve shell, *Estheria minuta*, is found in sandstones belonging to the uppermost part of the Keuper in Worcestershire and Warwickshire. Also found in the Keuper of Germany.

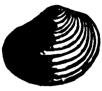

Fig. 71.
Estheria minuta.
Keuper, England and Germany.

REPTILES.—Footprints resembling the human hand occur in Bunter flagstones at Horton Hill, near Liverpool, and other places. Similar marks were long since observed in the Bunter-Sandstein of Germany, and were referred to an unknown animal called *Cheirotherium*. The footprints indicate an animal allied to the frog, but very much larger. Teeth of such an animal have been found. Sections of these teeth show peculiar labyrinth-like windings, hence the animal is called *Labyrinthodon*. It disappears at the close of the Trias, and the footprints with it. Footprints of other reptiles occur in the waterstones, and other parts of the Trias in England.

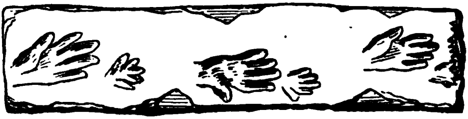

Fig. 72.—Footprints of *Cheirotherium* (Labyrinthodon).

Reptiles are far more numerous in the Trias than in any earlier rocks. At Elgin, in Scotland, several reptiles have been found in strata of uncertain age, by some referred to the Trias, by others to the Devonian. These reptiles are *Telerpeton*, *Hyperodapedon*, and *Staganolepis*, the latter quite crocodilian in its affinities. In the Bunter and Muschelkalk of Germany many others occur. *Nothosaurus* and *Rhyncosaurus* may be mentioned. In the Dolomitic Conglomerates of Bristol, *Thecodontosaurus* and *Palæosaurus* are found.

Birds.—Footprints of birds occur in the Connecticut Valley, in North America.

Mammals.—Teeth of a small mammal, of the nature of a kangaroo, have been found in the Marls at the top of the Keuper in England and Germany. This earliest known mammal is called *Microlestes antiquus*.[1] In North Carolina are found jaws and teeth of an allied animal called *Dromotherium sylvestre*.

148. Conditions under which the Trias was Deposited.—We find the Triassic strata in England resting upon the uptilted and denuded edges of Permian and older rocks, showing how much the latter were disturbed and destroyed before the deposition of the Trias began. It would seem from the great break which exists between the Trias and older rocks in Europe, and even wider districts, that a great continental surface existed, of which England formed part. At length portions of this continent were depressed, and the Trias deposited.

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[1] Gr. *micros*, little; *lestes*, beast of prey.

The lacustrine character of the Trias is established by similar evidence to that adduced in the case of the "Old Red" and Permian. Additional proofs are presented in the case of the Keuper, by the beds of rock-salt and gypsum, the mode of origin of which has already been considered (85, 86). While it is certain that the Triassic lakes were very salt at the time of the Keuper, they may have been partly fresh or brackish when the Bunter was deposited.

From the commencement of the "Old Red," until the close of the Triassic period, we have continual evidence of a long continental period, broken only by the marine beds of the Carboniferous. This evidence consists, as we have seen, partly of widely-distributed terrestrial and lacustrine deposits, and partly of almost world-wide disturbances and denudations giving rise to unconformities.

RHAETIC AND PENARTH BEDS.

Beds of Passage.

149. Rhaetic and Penarth Beds.—On the Continent of Europe, between the Keuper and the Lias, there intervene large and important deposits, known as the St Cassian and Kössen beds, or, collectively, the Rhaetic[1] beds. These beds are represented in our own islands by a comparatively thin but interesting band, known as the Penarth beds, so called from Penarth, near Cardiff, where the cliffs exhibit them well. These beds also occur in the neighbourhood of Axmouth, at Aust, and other places on the borders of the Bristol Channel. They also occur in Staffordshire, and several other places along the junction of the Keuper and the Lower Lias. Beds of this age occur at Lisnagrib, and near Belfast, in Ireland.

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[1] From *Rhaetia,* the ancient name of Lombardy.

These beds are always conformable to the Trias and the Lias. They form in fact "beds of passage," by which name they are known.

The highest member of the series is the *White Lias*, a hard and fine-grained rock, generally unfossiliferous.

The so-called "Landscape Marble," found at Cotham, near Bristol, occurs at or near the base of the White Lias.

Below the White Lias come a series of black shales, known as the *Paper Shales*, containing fossil shells; and interstratified with it is the celebrated *Bone Bed*, made up almost entirely of the bones of fishes or reptiles. Below the *Paper Shales* are a series of marls, passing gradually into the Keuper Marls beneath them.

150. Rhaetic and Penarth Fossils.—In England and Wales the lamellibranchiate shells *Avicula contorta* and *Cardium Rhaeticum* are very characteristic. They also characterise Continental beds. So generally prevalent is the former, that the Rhaetic series is sometimes known as the *Avicula contorta Zone.*

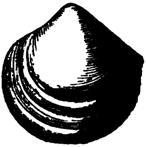

Fig. 73.—*Cardium Rhaeticum.*

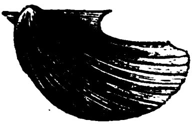

Fig. 74.—*Avicula contorta.*

Teeth and bones of fishes, such as *Gyrolepis*, *Hybodus*, *Acrodus*, and others, occur in the bone bed. Reptilian remains, together with teeth of *Microlestes*, occur in this zone.

In the St Cassian beds (Austrian Alps) a remarkable commingling of Palæozoic and Triassic with newer

Mesozoic forms occurs; for instance, *Orthoceras* and *Goniatites* occur with *Ammonites* and *Belemnites.*

JURASSIC SYSTEM.

Lias and Oolite.

151. Liassic and Oolitic Rocks.—The Rhaetic beds in England pass upwards into a series of rocks called the *Lias,* the latter in its turn being succeeded, quite conformably, by the *Oolite,* a series so called from the prevalence in it of limestones having an oolitic structure (24). In England the Lias and Oolite form a belt, averaging about thirty miles in width, and extending from Dorset to Yorkshire.

The Lias and Oolite are closely connected by their fossils, and are included in one system, *the Jurassic,* so named from the occurrence of this series in the Jura Mountains, in the east of France.

Succession in England:—

			Feet.
OOLITE,	*Upper,*	Portland Oolite, ...	170
		Kimmeridge Clay, ...	600
	Middle,	Coral Rag, ...	250
		Oxford Clay, ...	600
	Lower,	Cornbrash, ...	40
		Forest Marble, ...	500
		Bath Oolite (Great Oolite), . .	130
		Stonesfield Slate, ...	
		Fuller's Earth, ...	400
		Inferior Oolite, ...	250
LIAS,	*Upper,*	Upper Lias Clay and Sand, . .	550
	Middle,	Marlstone, ...	200
	Lower,	Lower Lias Clay and Limestone,	600

The Lias and Oolite form one conformable series, with a gentle dip to the east, the various members coming to the surface in succession, and running parallel to each other, sometimes along the whole belt. The unequal hardness of the different members has given rise by denudation to many minor escarpments facing west, besides the more prominent ridge where the Lower Oolite overlooks the Lias (122).

The Liassic series is characterised by laminated clays, and the Oolite by limestones.

Lower Lias.—This formation consists of blue clays and shales, with occasional bands of limestone. Nodules of argillaceous limestone occur in some places, which, when ground, form excellent cement.

Marlstone.—This member consists chiefly of calcareous and argillaceous sandstones. It is well exhibited near Cheltenham, where it is 200 feet thick. It frequently contains iron ore, which mineral is obtained from it in great abundance at Cleveland, in Yorkshire.

Upper Lias.—Principally a thick blue clay, upon which rest marly sands, these being capped by a band called the *Cephalopoda bed*, and which is regarded as the uppermost limit of the Lias. The upper Lias in Yorkshire contains beds of lignite, in which nodules of jet occur.

Inferior Oolite.—This formation attains in the neighbourhood of Cheltenham a thickness of 250 feet. It consists of a succession of shelly and oolitic limestones, many of which form good building stones. In Yorkshire the Inferior Oolite becomes a succession of shales, sandstones, and thin seams of coal, some of which are actually worked, such as the Moorland coal of Yorkshire.

Fuller's Earth.—A series of clays and thin limestones. The clay was formerly used by fullers in the preparation of their cloth, hence the name of the formation. The Fuller's Earth extends from Dorset to Gloucestershire, beyond which it thins out, and soon disappears.

Great or Bath Oolite.—The lowest member of this series is the *Stonesfield Slate*, a shelly limestone, easily splitting into slabs, and very rich in organic remains, including insects, reptiles, and the lower jaws of mammalia. The Great Oolite proper is remarkable for its thick Oolitic limestone, largely quarried for building purposes. Westminster Abbey is in great part built of this stone. Corals and stone-lilies are common. A local series, the *Bradford Clay*, succeeds the Great Oolite.

Forest Marble.—Principally a shelly limestone, occurring, among other places, at Wychwood Forest, in Oxfordshire. Its sandstones are often ripple-marked.

Cornbrash.—A thin series of sandy limestones, easily crushed. Its soil is considered to form good corn land.

Oxford Clay.—This formation, with the *Coral Rag* above it, constitutes the "Middle Oolite." It is a thick bed of clay, extending along the whole range of the Oolitic belt, including the district on which Oxford stands.

Coral Rag.—This is to some extent an old consolidated coral reef, corals being very plentiful, and most of them undisturbed from their original position in the reef.

Kimmeridge Clay.—This is the base of the "Upper Oolite." It consists of clays and shales, with a bed of lignite at Kimmeridge, on the coast of Dorset.

Portland Oolite.—This, the highest member of the series, has been named from the Isle of Portland, where it occurs as sandy beds below, covered by calcareous beds, at the top of which is the limestone known as Portland stone, largely used for building purposes. St Paul's Cathedral is built of this stone.

152. Liassic Fossils.—In passing upwards from the Trias and Rhaetic formations, a great change in the development of life is observed, the rocks, from the base of the Lias to the top of the Oolites, teeming with fossils, among which almost all classes of animals are represented.

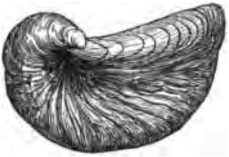

Fig. 75.
Gryphæa incurva.
Lias.

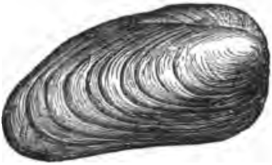

Fig. 76.
Hippopodium ponderosum.
Lower Lias, Cheltenham.

Plants.—*Cycads*, and *Ferns* with a network of veins on their fronds, are characteristic.

Brachiopoda.—Spirifers occur for the last time (genus *Spiriferina*). The genera *Rhynconella* and *Terebratula* are common.

Conchifera.—The genera *Ostrea* (oyster), *Gryphæa* (Fig. 75), *Lima*, *Avicula*, and many others, are abundant. *Hippopodium ponderosum* (Fig. 76) is peculiar to the Lower Lias.

Cephalopoda.—The Lias in England is sharply separated from the Rhaetic beds by the sudden appearance of *Ammonites* and *Belemnites* (Figs. 77, 78), which genera particularly characterise the Mesozoic formations from the Lias to the Chalk. The *species* of the Ammonite seem to have been comparatively short-lived, hence the Lias is divided into zones characterised by particular Ammonites.

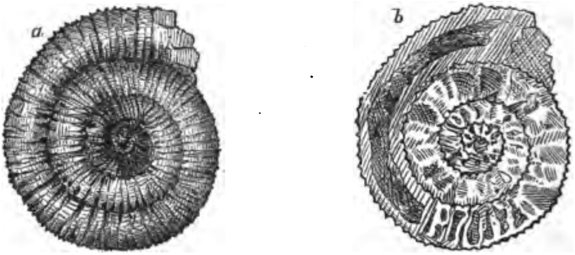

Fig. 77.—*Ammonites communis*. Lias.
a Exterior; *b* section.

The parts of the Belemnites most frequently found fossil are hard conical bodies, popularly called "thunderbolts." Many of these exhibit, at the broader end, a depression, in which originally fitted a chambered shell, less often preserved. Several species of *Nautilus* occur.

Echinodermata.—Among these the stone-lily of the Lower Lias, named *Extracrinus Briareus*, is characteristic, and so abundant at Lyme Regis and some other places, as to form thick beds with their broken stems and branches.

INSECTS.—An "insect bed" occurs at the base of the Lower Lias, and another at the base of the Upper Lias. In these, beetles, crickets, dragon flies, and other insects have been found.

FISHES.—The most remarkable are—*Dapedius*, with scales set like a Mosaic pavement; *Lepidotus*, *Acrodus*, with powerful teeth adapted for crushing the molluscs on which it lived; and *Hybodus*, with shark-like teeth.

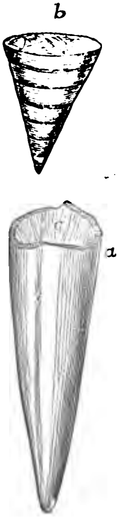

Fig. 78.—*Belemnite.* *a* solid cone; *b* chambered phragmocone; *c* alveolus, or socket, into which the phragmocone fits.

REPTILES.—The Lias is remarkable for its fossil reptiles. It, together with the Oolite, has been called the "Age of Reptiles," from the great development of these animals, both in size and numbers. *Ichthyosaurus*, *Plesiosaurus*, and *Pterodactylus* are the genera best known. The *Ichthyosaurus* was a huge fish-like lizard, often attaining a length of 25 feet. Its tail was long, and ended in a powerful tail-fin, while its anterior members were modified to serve as paddles. Its jaws and teeth were formidable; and the remains of fishes and reptiles sometimes found within its skeleton indicate its carnivorous habits. The *Plesiosaurus* had a long swan-like neck and crocodile-like head; its paddles were larger than those of the Ichthyosaurus, while its tail was shorter. The *Pterodactylus* was provided with wings, and could fly

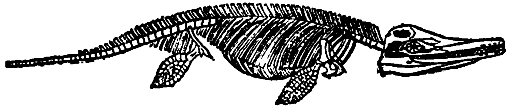

Fig. 79.—*Ichthyosaurus communis.* Restored skeleton.

like a bat. One of its digits was much extended, and supported the wing.

153. Oolitic Fossils.—Between the Lias and Oolite there is a break in the succession of life, only 37 species of Mollusca out of 256 present in the Upper Lias passing from it to the Inferior Oolite; but this is scarcely any greater break than is observed between some of the members of the Oolite itself.

PLANTS.—Similar to those of the Lias.

BRACHIOPODA are very abundant, as are all classes of fossil shells. *Terebratula* and *Rhynconella* are the genera most common. *T. fimbria, T. digona, T. carinata, R. spinosa,* and *R. varians,* are well-known species.

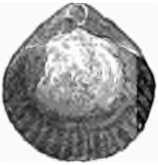

Fig. 80.
Terebratula fimbria.

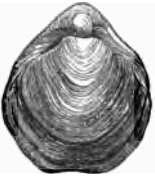

Fig. 81.
Terebratula carinata.

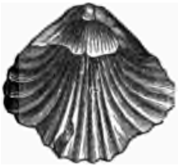

Fig. 82.
Rhynconella.

CONCHIFERA occur in great numbers and variety.

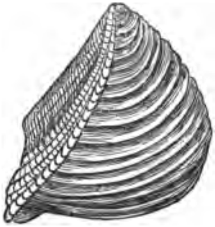

Fig. 83.
Trigonia costata.
Lower and Middle Oolite.

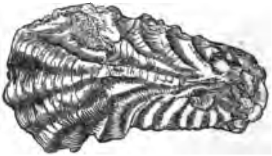

Fig. 84.
Ostrea flabelloides.
Lower Oolite.

Among the characteristic genera are *Ostrea, Cardium, Trigonia, Lima, Pholodomya,* and *Modiola.*

Gasteropoda.—*Pleurotomaria* and *Nerinea* are common. *Cerithium Portlandicum* is a common fossil in the Portland Oolite.

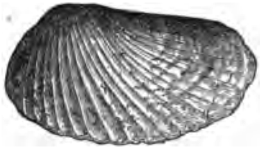

Fig. 85.
Pholodomya fidicula.
Lower Oolite.

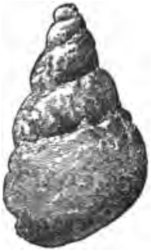

Fig. 86.
Chemnitzia.
Lower Oolite.

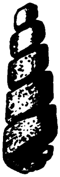

Fig. 87.
Cerithium Portlandicum (cast).
Portland Oolite.

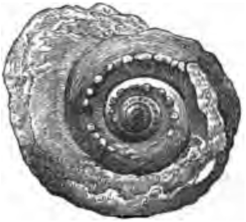

Fig. 88.
Pleurotomaria ornata.
Lower Oolite.

Cephalopoda.—*Ammonites* and *Belemnites* are very abundant. *A. Humphresianus*, *A. Parkinsoni*, *B. ellipticus* in the Lower Oolite; *A. Jason*, *B. hastatus* in the Middle Oolite; and *A. biplex* in the Upper Oolite, are characteristic species.

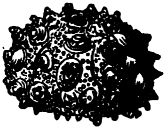

Fig. 89.
Cidaris coronata.
Middle Oolite.

Echinodermata.—Stone-lilies, such as *Apiocrinus*, and sea-urchins, such as *Cidaris*, are common.

Reptiles.—*Ichthyosaurus*, *Plesiosaurus*, *Pterodactylus*. Also *Megalosaurus* and *Cetio-*

saurus, huge lizards with long legs, lifting them from the ground.

BIRDS.—The oldest known bird is the *Archæopteryx*, an almost entire skeleton of which was discovered in 1862 in the lithographic stone of Solenhofen in Bavaria. Not only were the bones preserved, but even impressions of many of the feathers. The specimen is now in the British Museum.

MAMMALIA.—Lower jaws of four species of mammals belonging to three genera have been found in the Stonesfield Slate. The genera are *Amphitherium*, *Phascolotherium*, and *Stereognathus*. They were all pouched animals, like the kangaroo, or closely allied to it.

154. Conditions under which the Lias and Oolite were Deposited.—The abundance of sea-shells, encrinites, and corals, show the Lias and Oolite to be true marine deposits. There is, however, evidence of the nearness of land, almost throughout the British deposits. The land-plants and insects, reptiles and mammals, show land to have been near, while the ripple-marks and oyster-beds, occurring here and there, indicate actual sea-beaches. The British Palæozoic districts appear to have been above water at this time, for the Oolitic deposits thin away towards the west, the Cretaceous strata subsequently overlapping them (122). The Palæozoic districts of Devonshire, Wales, Cumberland, the Highlands of Scotland, and others, probably formed a group of islands in the seas about which the Lias and Oolite were deposited.

The tree-ferns, cycads, large reptiles, and coral reefs of this series indicate a warm climate, probably sub-tropical.

Although a strict conformability is maintained throughout the Liassic and Oolitic series in the English district, yet the frequent change in the nature of the deposits, and breaks in the succession of life, indicate geographical changes, these disturbances sometimes affecting the immediate area of the Oolitic seas. We have evidence of this in the Lower Oolites of Northamptonshire, Lincolnshire, and Yorkshire, where this series is partly marine, and partly a succession of estuarine, fresh-water, and terrestrial beds.

WEALDEN AND PURBECK FORMATIONS.

155. Wealden and Purbeck Strata.—In the Isle of Purbeck, Dorset, the Upper Oolite is conformably succeeded by a series called the *Purbeck Beds;* and these in their turn pass upwards into strata, the equivalents of which are largely developed in the south-east of England, occupying the district between the North and South Downs known as the Weald of Kent, and are hence called *Wealden.* Strata of the Purbeck and Wealden age also occur in the Isle of Wight and in the Isle of Portland.

Succession :—

WEALDEN SERIES, . .	Weald Clay, . .	600 feet.
	Hastings Sands, .	900 ,,
PURBECK BEDS, ...	Upper, Middle, Lower, ...	150 ,,

Purbeck Beds.—This is a pile of numerous thin beds of limestone, shales, etc., some of which are fresh-water and others marine. In the Lower Purbeck there is a remarkable stratum called the "Dirt Bed." It is twelve to eighteen inches thick, of a brownish colour, and contains silicified roots, erect stumps of trees, and prostrate trunks. The "Purbeck Marble," formerly much in request for the internal decoration of churches, was obtained from the Upper Purbeck. This "marble" consists almost entirely of fresh-water shells (*Paludina*).

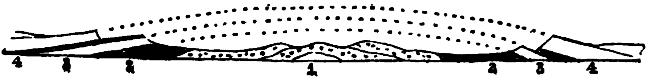

Fig. 90.—Section from the North to the South Downs across the Weald.
1. Hastings Sand. 2. Weald Clay. 3. Lower Greensand.
4. Upper Cretaceous Strata.

Wealden Series.—In the Wealden area the strata have been heaved into a dome-like form: the upper portion of the dome, consisting of Cretaceous strata and Weald Clay, have since been removed, exposing the Hastings Sands in the central portions of the area. This series chiefly consists of fresh-water strata, with marine interstratifications.

At Speeton, on the coast of Yorkshire, beds occur which are believed to be the marine equivalents of the fresh-water Wealden strata, and to correspond to the series called Middle and Lower Neocomian,[1] on the Continent.

156. Wealden and Purbeck Fossils.

PLANTS.—Cycads, ferns, and others; in general nature resembling the Jurassic.

SHELLS.—The majority are fresh-water and estuarine. Among the fresh-water gasteropods are *Paludina*, *Limnea*, and *Physa;* and among the fresh-water conchifers are *Unio* and *Cyrena*.

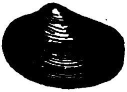

Fig. 91.
Cyrena elongata.
Purbeck.

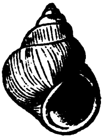

Fig. 92.
Paludina fluviorum.
Wealden.

CRUSTACEA.—Minute species of *Cypris* occur in millions.

REPTILES.—The Wealden reptile *Iguanodon* was a vegetable feeder of large dimensions. It stood erect upon its legs like the *Cetiosaurus*, and was taller than an elephant. It derived its name from the form of its tooth, which is shaped like that of the living Iguana. Remains of *Cetiosaurus*, *Hylæosaurus*, *Chelone*, and other reptiles, are found in the Wealden formation.

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[1] From *Neocomum*, the classical name of Neufchatel, in Switzerland.

Mammals.—The Middle Purbeck at Swanage has yielded no fewer than fourteen species of mammals. Among these are *Galestes* and *Plagiaulax.*

157. Conditions under which the Wealden and Purbeck Beds were Deposited.—After the close of the Oolitic period, it seems that the south and centre of England, together with other districts, were raised above the sea-level and subjected to all the destructive operations of denudation for a long period of time. England, no doubt, at that time formed part of a great continent, for the Wealden and Purbeck Beds appear to be parts of the delta of an immense river, so large that it could only have been supplied by the drainage of an extensive continent.

In the Wealden and Purbeck series, the fresh-water shells and reptilian remains are sufficient indication of the fresh-water beds, while the interstratification of marine beds shows the whole series to have been deposited in a spot where the water was usually fresh, but where the sea occasionally gained access. This would be the case in the estuary of a large river.

It is probable that the mass of the continent, across which the great Wealden river flowed, lay to the north and west; for we have seen that at Speeton the contemporaneous beds were marine, and similar beds occur in Switzerland and other places to the south and east.

Cretaceous Formations.

Upper Mesozoic.

158. Cretaceous Rocks.—In the Wealden area, and in the Isle of Wight, the Weald Clay passes upwards into the lowest member of a series of formations called the *Cretaceous,*[1] so named from the thick beds of chalk which form a considerable part of this series.

The Cretaceous formations show themselves in England principally as a broad belt running parallel to the Oolite from Dorset to Norfolk. To the east of Salisbury Plain the area widens, and dividing into two parts, becomes the North and South Downs. The southern half of the Isle of Wight is also covered by Cretaceous strata. In the neighbourhood of the Wash, the Cretaceous series are covered by newer deposits, but reappear in Lincolnshire, and trending northwards, terminate at Flamborough Head in Yorkshire. The English Chalk is continuous with that of the Continent, which extends to the Mediterranean; the shallow Straits of Dover being merely a channel cut in the chalk by the sea.

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[1] Lat. *creta,* chalk.

Succession:—

UPPER CRETACEOUS,	Maestricht and Faxoe Beds (absent in England).	
	White Chalk, with flints, .	1000 feet.
	White Chalk, without flints,	600 ,,
	Chalk Marl, ...	100 ,,
	Upper Greensand, ...	150 ,,
	Gault, ...	200 ,,
LOWER CRETACEOUS or UPPER NEOCOMIAN,	Lower Greensand, Atherfield Clay, ...	850 ,,

Lower Cretaceous.—This consists of the Atherfield Clay and the Lower Greensand, and represents the upper division of the Continental series called Neocomian (155). The Atherfield Clay rests upon the Weald Clay in the Isle of Wight, the principal difference between the two being, that the Weald Clay contains fresh-water shells, while the Atherfield Clay does not. The Lower Greensand is closely connected with the Atherfield Clay; it has derived its name from the prevalence in it of particles of silicate of iron, which often gives a green tinge to the beds.

Gault.—This formation lies somewhat unconformably upon the Greensand. It consists of a dark-blue clay or marl, and contains many fossils, often beautifully preserved.

Upper Greensand or Chloritic Series.—This formation consists chiefly of a calcareous sandstone, and somewhat resembles the Lower Greensand in appearance, but is insignificant in importance when compared with it. It varies in thickness and character in different places. In Surrey it is quarried as a firestone. In some places, as at Farnham, in Surrey, nodules of phosphate of lime occur, and in such abundance as to be worked for the manufacture of artificial manure. These nodules are evidently of organic origin. In this so-called "coprolite bed" have been found the remains of a bird and many reptiles.

White Chalk.—The Upper Greensand passes into the Chalk Marl, and the latter into the White Chalk. Chalk, it is well known, is a soft and very pure variety of limestone. Under the microscope it is seen to be mainly made up of the calcareous shells of foraminifera, which is precisely the nature of the ooze now forming at the bottom of the deep Atlantic (82). The White Chalk is separated into two divisions, the upper being characterised by the presence of flints, which are absent in the lower. The nodular flints occur in rows, and indicate the planes of stratification, which are otherwise obscure, although joints are numerous. *Flints* consist of silica, and owe their origin to the abstraction of silica from the sea-water by certain forms of organic life (83). The silica derived from the siliceous coatings of microscopic organisms falling to the bottom of the sea, in lapse of time collects about sponges or other siliceous centres, and in this way forms flints. When broken through, flints often exhibit the structure of the original sponge or other organic body about which the silica gathered. Flints not only occur as nodules, but frequently as layers, and sometimes as peculiar vertical veins called "pot-stones."

Chalk districts resemble Carboniferous Limestone districts in their scarps, dales, and other physical features, but on a smaller scale. The north-east side of the belt of Chalk which crosses England forms a prominent escarpment, similar to that of the Oolite, but smaller.

Deep borings made for water in the London area show that there the Cretaceous series do not rest upon Oolitic but upon Palæozoic rocks.

Cretaceous strata occur in the north-east of Ireland. The Chalk is here much harder than the English Chalk.

At Aix-la-Chapelle, in Germany, the White Chalk and Chalk Marl of England are represented by white sands and laminated clays 400 feet in thickness. This formation is remarkable for the abundance of terrestrial plants it contains, many of which are in a beautiful state of preservation.

In England we have no Cretaceous strata newer than the White Chalk with flints. On the Continent, at Maestricht, on the banks of the Meuse, in Holland, the Chalk with flints is succeeded by limestones without flints, and containing *Belemnites*, *Baculites*, *Hamites*, and other characteristic Cretaceous fossils. At Faxoe, also, in the Isle of Zealand, Denmark, strata of similar age occur, containing somewhat similar fossils.

159. **Cretaceous Fossils.**—On passing from the Wealden series to the Cretaceous, we at once lose all the fresh-water shells, while true marine species take their place, and exclusively occur throughout. Some terrestrial species, such as *Iguanodon Mantelli*, are common to the Wealden and Lower Greensand.

Compared with the Oolite, the Cretaceous forms are quite new, not a single Oolitic species being found in Cretaceous strata.

The break in the succession of life between the Upper and Lower Cretaceous is well illustrated by the species of Ammonites they contain. The Lower Greensand has 31, and the Gault 21, only three of these being common to the two formations.

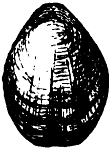

Fig. 93.
Terebratula biplicata.
Upper Cretaceous.

FORAMINIFERA.—Many of these strikingly resemble the foraminifera now living in the Atlantic, and other seas (Fig. 13).

BRACHIOPODA still decline in numbers compared with the Conchifera. *Terebratula biplicata* and *T. striata* are common species.

CONCHIFERA.—The genera *Ostrea*, *Lima*, *Pecten*, and others, are numerous. Two characteristic species are figured.

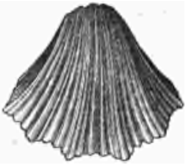

Fig. 94.
Pecten 5-costatus.
Upper Cretaceous.

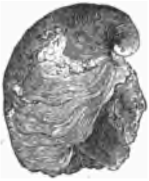

Fig. 95.
Exogyra columba.
Upper Greensand.

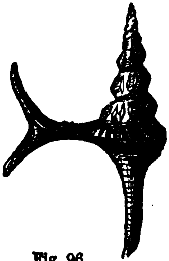

Fig. 96.
Rostellaria carinata.
Gault.

GASTEROPODA.—*Rostellaria carinata* is a characteristic and beautiful species.

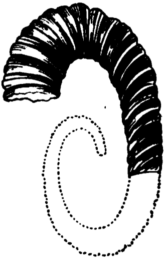

Fig. 97.
Hamites.
Upper Cretaceous.

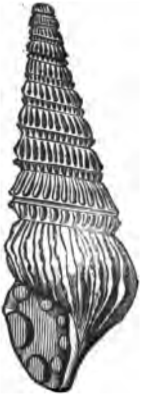

Fig. 98.
Turrilites costatus.
White Chalk.

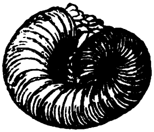

Fig. 99.
Scaphites.
White Chalk.

CEPHALOPODA.—*Ammonites*, *Belemnites*, and *Nautilus* occur, also several genera peculiar to the Cretaceous series, such as *Hamites*, *Baculites*, *Scaphites*, and *Turrilites*.

ECHINODERMATA. — Sea-urchins are very prevalent. Among these are the genera *Ananchytes*, *Galerites*, *Micraster*, and others. The crinoid *Marsupites* is also prevalent and characteristic.

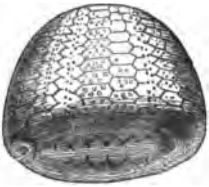

Fig. 100.
Ananchytes ovatus.
White Chalk.

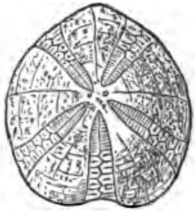

Fig. 101.
Micraster cor-anguinum.
White Chalk.

REPTILES.—The genera *Ichthyosaurus*, *Plesiosaurus*, and *Pterodactylus* occur for the last time in the White Chalk, while several new genera, as *Mososaurus*, are peculiar to the Chalk itself.

BIRDS.—Two species, each about the size of a pigeon, have been obtained from the Upper Greensand, near Cambridge.

160. Conditions under which the Cretaceous Series were Deposited.—We have seen that the fresh-water Wealden series are succeeded almost insensibly by the marine Lower Cretaceous series. This indicates that a subsidence of the Wealden area at least took place; and this, without occupying any very great lapse of time, seeing that some of the terrestrial species are common to both the Weald Clay and the Lower Cretaceous.

The widely-spread Cretaceous strata show that the subsidence of the continent of which England formed part was very general. After the deposition of the Lower Greensand, portions of the British area, at least, became land and suffered denudation, and subsequently subsiding, the Gault was thrown unconformably upon the Lower Greensand. The subsidence continuing, the various members of the Upper Cretaceous were deposited, each overlapping its predecessor, until the White Chalk, deposited, no doubt, in a very deep sea, overlapped all, and abutted on the mountains of Wales, and other of the old Oolitic islands, or perhaps quite covered them; extending still further to the west, this formation also covered part at least of what is now Ireland. To the south-east the Cretaceous seas were extensive; but at some places, as at Aix-la-Chapelle, the fossils indicate nearness of land.

The great break in the succession of life between the Marine Oolitic and Cretaceous series cannot be wondered at when we think of the long continental period which intervened between them, represented only in the most fragmentary manner by the great delta deposits of the Purbeck and Wealden.

CHAPTER XVI.

CAINOZOIC OR TERTIARY PERIOD—EOCENE, MIOCENE, AND PLIOCENE FORMATIONS.

161. Classification of the Tertiary Strata.—With the exception of a few Cretaceous foraminifera, not a single *species* of animal or plant belonging to the Palæozoic or Mesozoic rocks is found living now. In strata newer than the Chalk the case is different; a proportion of the species are identical with living ones, and this proportion steadily increases from the time of the Older Tertiary rocks until now. The classification of Tertiary formations is based on this increase, the strata being divided into three groups, as follows:—

NEWER TERTIARY,	Newer Pliocene,[1]	95 species.
	Older Pliocene (more recent),	50 ,,
OLDER TERTIARY,	Miocene[2] (less recent), .	25 ,,
	Eocene[3] (dawn of recent things),	5 ,,

The numbers give the approximate percentage of the maximum number of shells which are identical with living species. In the case of the Eocene, it is doubtful if a single species of its shells is living now.

EOCENE FORMATIONS.

162. Eocene Strata.—The Chalk in the neighbourhood of London, and again in Hampshire and the Isle of Wight, is covered by the group of formations called *Eocene.* These formations appear to be conformable to the Chalk, so far as the lie of the strata is concerned; but that there is an immense interval between them is shown by the great break in the succession of life presently to be considered.

The Eocene strata in England are now confined to two synclinal hollows—the *London basin* and the *Hampshire basin,* the latter including the northern half of the Isle of Wight. Eocene strata occur in the district of Paris, forming the *Paris basin,* and in the Netherlands.

SUCCESSION IN ENGLAND.

		Feet.	
Upper,	Hempstead Beds, ...	170	Fluvio-Marine.
	Bembridge Beds, ...	115	
	Osborne Beds, ...	70	
	Headon Beds, ...	200	
Middle,	Bagshot, Bracklesham, and Barton Beds,	1270	Marine.
Lower,	London Clay, ...	480	Marine.
	Plastic Clay (Woolwich and Reading Beds),	160	Estuarine.
	Thanet Sands, ...	90	Marine and Estuarine.

Thanet Sands.—Light-coloured sands occurring in the

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[1] Gr. *pleion,* more; *kainos,* recent.
[2] Gr. *meion,* less.
[3] Gr. *eos,* dawn.

London basin, thickest in the east, and thinning away to the west. Below these beds is a stratum of chalk flints, indicating that the Chalk had suffered erosion before these beds were deposited.

Plastic Clay.—Clays and sands of various colours and shades. Fresh-water and marine shells occur alternately, showing them to be of an estuarine character. Unlike the Thanet sands, these beds become thicker from east to west, being principally developed in the neighbourhood of Reading and in the Isle of Wight, where they repose directly on the Chalk.

London Clay.—Brown and bluish clays, with sands, and bands of concretions called *septaria,* from which Roman cement is manufactured. The clay is largely used for brickmaking. Besides marine shells, fossil fruits of palms, remains of crocodiles, turtles, and a large sea-snake, have been found in this formation.

Middle Eocene.—The Bagshot series consist of unconsolidated sands and clays. Only sparingly fossiliferous about Bagshot, but at Bracklesham and Barton on the Hampshire coast, rich in fossil shells and other species of a tropical or sub-tropical character. The whole series are well seen in section in the Isle of Wight. On the Continent, strata of this age are extensively developed; they form a large part of the great mountain axis extending from the Pyrenees to India. The Middle Eocene is characterised by a large foraminifer named *Nummulites,* which is so abundant in some places on the Continent as to form thick limestones of its calcareous coverings—the *Nummulitic Limestone,* of which some of the Pyramids are built.

Upper Eocene or Fluvio-Marine Series.—These are absent from the London basin. They occupy the northern half of the Isle of Wight, and a district of about equal extent on the other side of the Solent. The *Headon Beds* consist of white and green marls and limestones. They are exhibited in section at Headon Hill and other places in the Isle of Wight. Of the three portions into which they are divided, the lower and upper are fresh-water, while the middle is brackish and marine. The *Osborne Series* (from Osborne, Isle of Wight) consists of sands and gritstones, with a bed of limestone quarried for building purposes. The shells are of fresh-water or brackish-water species. The *Bembridge Beds* consist of marls, clays, and limestones, of fresh-water, brackish, and marine origin. These represent the gypsum of Montmartre, near Paris, in which have been found about fifty species of mammals, often entire, and in a fine state of preservation. The *Hempstead Beds* consist of marls and sands, and lie upon the Bembridge Beds in the Isle of Wight. The lower beds are carbonaceous, especially the lowest one of all—the "Black Band." The plants resemble those of the succeeding Miocene age, and on this account these beds are sometimes grouped with the Miocene formations.

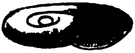

Fig. 102.
Planorbis discus.
Upper Eocene.

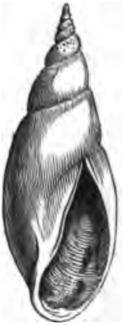

Fig. 103.
Limnea longiscata.
Upper Eocene.

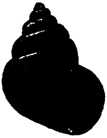

Fig. 104.
Paludina orbicularis.
Upper Eocene.

163. **Eocene Fossils.**—On comparing Eocene fossils with those of the Chalk, we observe a very abrupt break in the succession of life; not a single species is common to the two, and many of the characteristic Mesozoic

genera are quite unknown above the Chalk. Among these may be mentioned *Gryphæa*, *Ammonites*, *Belemnites*, *Hamites*, and *Scaphites*; also *Ichthyosaurus*, *Plesiosaurus*, *Pterodactylus*, and their congeners. While the Mesozoic period is deservedly called the "Age of Reptiles," the Tertiary period claims to be the "Age of Mammals."

PLANTS.—Remains of tree-ferns, palms, custard apples, bread-fruit trees, gourds, melons, and other tropical plants, are found in the London clay.

FORAMINIFERA.—*Nummulites* are very characteristic of the Middle Eocene in England and on the Continent.

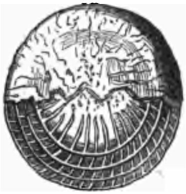

Fig. 105.
Nummulites lævigatus.
Middle Eocene.

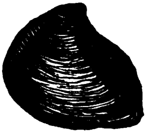

Fig. 106.
Cryptodon angulatum.
London Clay.

FRESH-WATER SHELLS.—The conchifer *Cyrena* and the gasteropods *Planorbis*, *Paludina*, and *Limnea*, are abundant in the fresh-water beds.

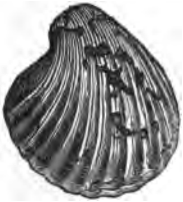

Fig. 107.
Cardita planicosta.
Middle Eocene.

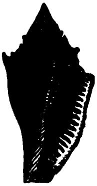

Fig. 108.
Voluta luctatrix.
Middle Eocene.

MARINE SHELLS.—Conchifera—*Cardium*, *Cardita*, *Cryptodon*, etc.; Gasteropoda—*Voluta*, *Fusus*, *Rostellaria*, *Turritella*, etc.; Cephalopoda—*Nautilus centralis.*

Fishes.—Teeth of *Lamna elegans*, *Otodus obliquus*, and others, abound in the Lower Eocene. Remains of the sword-fish and the saw-fish have been found in the London Clay.

Reptiles.—The London Clay has yielded turtles, a large sea-snake, and a true crocodile. Other species occur in the Upper Eocene of England and the Continent.

Mammals.—The pachyderms (thick-skinned)—*Coryphodon*, resembling the living tapir, but larger, and *Hyracotherium*, allied to the hog; an opossum and others in the London Clay. In the Upper Eocene of England and the Continent—*Palæotherium*, or "ancient beast," tapir-like, and about the size of a horse; *Anoplotherium*, or "harmless beast," a pachyderm with a long powerful tail; *Chæropotamus*, or "river-hog;" *Dichobune*, and others.

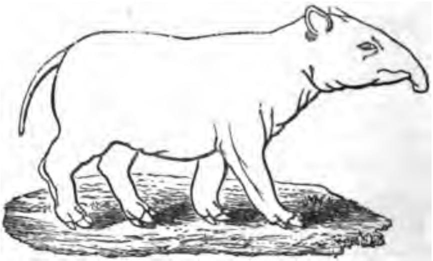

Fig. 109.—*Palæotherium magnum*. Restored outline.

164. Conditions under which the Eocene Strata were Deposited.—The great gap in the succession of life, in passing from the Chalk to the Eocene, indicates a long interval of time unrepresented by the deposition of strata. During this interval the Chalk must have been elevated, and have suffered denudation. Subsequently the south-west portion of England, together with other districts, were depressed, and became the seas and estuaries in which the Eocene deposits were made. The fresh-water beds, remains of land plants, insects, and terrestrial mammalia, occurring more or less throughout the series, show the nearness of land; and the prevalence of fresh- and brackish-water beds, both at the base of the series and at the upper part, seems to show that the whole series were deposited near the mouth of a considerable river, sometimes in the estuary, and sometimes—when a slight subsidence caused the spot to be further out at sea—in true sea-water, where only marine species could live. The palms, the crocodiles, turtles, shells, and other flora and fauna of the time, indicate a tropical climate, probably not unlike that of the East Indies at the present time.

After the emergence of the Chalk, England must have been joined to the Continent. The proof lies in the remains of the large mammals which make their appearance in different parts of the English Eocene deposits, these mammals having evidently *walked* over here from the Continent.

165. Disturbance and Denudation of Eocene Strata.—The synclinal curvature which the Eocene strata partake of, in common with the Chalk in the basins of London and Hampshire, shows that they have undergone disturbance since their deposition. As these strata in the south-west of England are everywhere conformable to the Chalk, so far as dip is concerned, it is probable that in this district they completely covered the Chalk, but have since been denuded from the anticlinal between the two basins. That this was the case is attested by small outliers of Eocene strata lying in this district. The original extension of the strata eastward is also proved by similar outlying patches, some of which occur near the extreme edge of the escarpment of the Chalk.

The synclinal giving rise to the Hampshire basin has brought up the Eocene and Cretaceous strata sharply at the south, many of the sections in the Isle of Wight showing the beds "on edge."

The anticlinal fold between the Eocene basins seems to have culminated in the Wealden area, and here denudation has proceeded furthest, for not only have the Eocene and Cretaceous strata been stripped away, but the Wealden series have been exposed almost to the base.

MIOCENE FORMATIONS.

166. Miocene Strata.—On the Continent of Europe the Eocene series pass upwards without any stratigraphical break into the series called *Miocene*. Miocene strata are largely developed in Europe and other parts of the world, but we have the merest trace of them in the British Isles.

At Bovey Tracey in Devon, Miocene strata occur under an accumulation of modern peat, as beds of clay and sand interstratified with bands of lignite. The beds are altogether about 300 feet thick, and cover a space ten miles long by two wide. They contain fresh-water shells and many plants, the latter resembling the Miocene flora of the Continent.

In the Isle of Mull, interstratified with volcanic lavas and ashes, there occur beds of clay and lignite, some of the clays, known as the "Miocene Leaf Beds of Mull," yielding leaves of plants identified as of Miocene age.

The Leaf Beds of Mull are important as fixing the geological date of extensive volcanic disturbances, which affected, not only Mull, but a great tract, embracing many of the Inner Hebrides, extending as far south as Antrim in Ireland, and northwards through the Faroe Isles to Iceland. All along this band the present islands appear to be the remnants of a succession of volcanic plateaux. The well-known basaltic rocks of Fingâl's Cave and the Giant's Causeway are volcanic products of this period.

Miocene rocks occur in the west and south of France; also in Auvergne, in Central France; they are here partly marine and partly fresh-water. Miocene strata occur in Belgium, on a large scale in Switzerland, in the basin of Vienna, in the Alps, on the flanks of the Himalayas, in the Sewalik Hills in India, in the United States, and other places.

In Iceland, Spitzbergen, and Greenland, Miocene beds occur, containing species of fossil plants indicating a temperate climate.

167. Miocene Fossils.—The flora is everywhere exceedingly abundant, very varied in character, and closely resembling that of the present day. It is remarkable that in Europe species of plants grew together, some of which have since migrated to Africa, some to Asia, and others to America, while some have remained and contributed to our present European flora. The plants and the mammalia are the most important fossils.

PLANTS.—At Bovey Tracey, evergreen oaks, fig-trees, vines, laurels, palms, trees of the cinnamon tribe, willows, beeches, and others.

MAMMALIA.—Extinct genera—*Deinotherium*, *Chœropotamus*, and others. Living genera—elephant, rhinoceros, hippopotamus, dolphin, opossum, giraffe, deer, monkey, and many others.

Many of the Miocene mammalia are interesting on account of their supplying "missing links," connecting many living genera whose relationship it were otherwise difficult to trace.

168. Conditions under which the Miocene Strata were Deposited.—Great Britain appears to have formed land in Miocene times, the deposits at Bovey Tracey having been made in a lake, and those at Mull accumulated in a marsh or shallow lake. Considerable portions of Southern Europe were beneath the sea, but other portions were continental, having many fresh-water lakes in which the Miocene fresh-water deposits were made. England, Iceland, and Greenland were all probably parts of this continent, judging from the similarity of their fossil plants.

The climate of Europe at this time, as gathered from the flora and fauna, was sub-tropical. This applies also to the south of England. The evergreen shrubs and other plants of the Arctic regions also indicate a warm climate, which is difficult to account for, unless by astronomical theories. The Alps at this time were probably but partly elevated, and certainly not sufficiently lofty to chill the air of Central Europe as they do now.

PLIOCENE FORMATIONS.

169. Pliocene Strata.—These occur in England in a few insignificant patches on or near the coast of Norfolk and Suffolk. They rest in some places on the London Clay, but chiefly repose directly on the Chalk. These beds are locally known as the "Crag," and are subdivided as follows:—

Newer Pliocene, .	Norwich Crag, .	20 feet.
Older Pliocene, . .	Red Crag, . .	50 ,,
	Coralline Crag, .	30 ,,

Coralline or White Crag.—This consists of soft marly sands of a white colour, with occasional thin bands of limestone. It is rich in marine fossils, but true corals are rare; the coral-like bodies it contains are in reality polyzoa.

Red Crag.—This consists of beds of sands and gravels coloured red by oxide of iron. The Coralline and Red Crags usually lie side by side, but in one or two places the Red Crag lies in hollows denuded in the Coralline. The Red Crag, like the Coralline, is rich in marine fossils, among which are limpets and other shallow-water shells. At the base of the Red Crag, where it rests on the Chalk, is a "bone bed," or layer of phosphatic nodules, containing in many cases the ear-bones of whales, teeth of sharks, and remains of large mammalia. A similar bed underlies the Coralline.

Norwich, Mammaliferous, or Fluvio-marine Crag.—This occurs in the neighbourhood of Norwich as small patches of sand, gravel, and loam, resting directly on the Chalk. It contains many marine fossils, and in addition twenty still living species of land and fresh-water shells. At the base of this Crag is a bed called the "Stone Bed," which is composed of large unrolled chalk-flints mingled with the bones and teeth of large mammals.

The Crags supply useful materials for agricultural purposes, the loose shelly sands and marls being used for spreading over ground deficient in calcareous matter, and the phosphatic nodules being ground for manure.

Pliocene strata occur round Antwerp in Belgium. They are here often consolidated, and contain many fossils, two-thirds of the species of which are the same as those of the Crag of Suffolk.

The Sub-Appenines, or low hills between the Appenines and the sea, are partly composed of Pliocene strata. Nearly half of Sicily is covered with strata of Newer Pliocene age, which is of great thickness, and elevated in some places 3000 feet above the sea. The Pliocene shell beds at a height of 1200 feet along the flanks of Etna indicate the recent origin of this mountain.

170. Pliocene Fossils.—In the English Pliocene formations the per centage of fossil shells identical with living species is considerably in excess of the Miocene. In the Coralline Crag the per centage is about 82, in the Red Crag 75, and in the Norwich Crag 69.

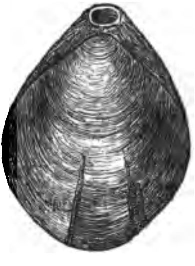

Fig. 110.
Terebratula grandis.

POLYZOA.—*Fascicularia* (now extinct), and others, are common.

MARINE SHELLS.—The brachiopod *Terebratula grandis* is characteristic, and so are the conchifers *Pectunculus variabilis*, *Astarte Omalii*, and *Cardita senilis*. The gasteropods *Fusus contrarius*, or reversed whelk, *Purdura tetragona*, and *Voluta Lamberti*, are very common in the Red Crag. The genus Nautilus is represented by *Nautilus centralis*.

MAMMALS.—Remains of the following have been found in the English Crag—viz., *whale*, *elephant*, *rhinoceros*, *tapir*, *pig*, *horse*, *bear*, *hyæna*, *deer*, *beaver*, and others; together with the extinct genera *Mastodon* (allied to elephant), and *Hipparion* (allied to horse).

171. Conditions under which the Pliocene strata were Deposited.—Great Britain does not give evidence of having suffered much disturbance in the interval between the Miocene and Pliocene periods. The Crags indicate that a portion of Norfolk and Suffolk was below the sea at the commencement of the Pliocene period, the Coralline Crag bearing evidence of having been deposited in a moderately deep sea. As the Red Crag lies unconformably upon the Coralline, the latter must have been elevated, denuded, and again depressed, before the former was deposited. The littoral[1] shells and cross stratification of the Red Crag show it to be a shallow-water accumulation; while the fresh-water and land shells mingled with the marine species of the Norwich Crag

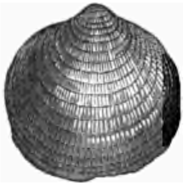

Fig. 111.
Pectunculus variabilis.

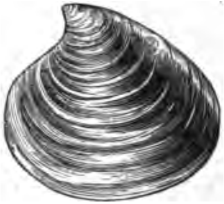

Fig. 112.
Astarte Omalii.

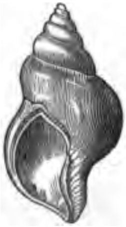

Fig. 113.
Fusus contrarius.

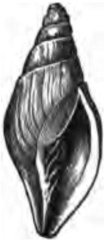

Fig. 114.
Voluta Lambertii.

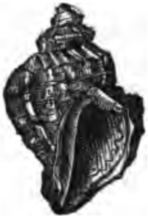

Fig. 115.
Purpura tetragona.

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[1] Lat. *littus, littoris,* a shore.

lead us to think it was deposited at the mouth of a river. Altogether the whole of the Crag formations resemble the deposits now forming in the German Ocean, and may be regarded as an elevated portion of the bed of that sea.

The climate seems to have gradually grown colder during Pliocene times. We trace the change from the Coralline Crag, which, of 240 existing species of shells, contains 28 species now only found in southern latitudes, to the Norwich Crag, which has no southern species, but many northern. It is probable, therefore, that during the Pliocene period the climate of this country fell from one rather warmer to one much colder than what we at present enjoy.

Some large blocks of porphyry and chalk flint found in the Coralline and Red Crags, suggest that icebergs occasionally reached these islands and were stranded on its shores.

It is generally thought that Great Britain was an island during the deposition of the Crag. It must, however, have been previously joined to the Continent, to allow of its becoming inhabited by new species of large mammalia, the remains of which occur in Pliocene strata.

CHAPTER XVII.

POST-PLIOCENE AND RECENT PERIODS—GLACIAL EPOCH—THE BOULDER CLAY—GLACIAL DRIFT—VALLEY GLACIERS.

172. Chillesford Beds.—At Chillesford in Suffolk, stratified deposits of yellow sands and clays occur which from their fossils are considered to be of more recent date than the Norwich Crag. The skeleton of a whale has been found in the upper laminated clays. The shells indicate a colder climate than those of the Crags, no less than two-thirds of the number now inhabiting the shores of Greenland or other northern countries.

173. Cromer Forest Bed.—This bed occurs at Cromer and other places on the shores of Norfolk. It is best seen at low water, especially if a rough wind has previously been blowing, when the sea will have removed the sand and mud from its surface. Under favourable circumstances the bed has been traced for forty miles along the coast. It consists chiefly of sandy clays, studded with roots and upright stumps of trees, and contains the remains of elephants and other mammalia. In the upper part of the bed are bands of lignite and fresh-water shells. The Forest Bed does not rest on the Crag, but its fossils are of newer type. The antiquity of the bed is evident from the great thickness of Boulder Clay (presently to be described) which rests upon it.

Among the flora of the Forest Bed are the Scotch fir, pine, yew, oak, sloe, alder, and water-lily. At least twenty species of terrestrial mammalia occur, half of which are now extinct, while the rest still survive in Europe. Among others are found remains of three species of elephant, rhinoceros, hippopotamus, horse, an animal resembling the tiger, bison, four species of bear, six of deer (including the so-called Irish elk), beaver, and mouse.

The large terrestrial mammalia of the Forest Bed indicate that at the time this bed formed land, England must have been joined to the Continent.

174. The Glacial Epoch.[1]—We have seen in the Pliocene strata evidence of a gradual change from a warm or mild climate to one much colder; and in the Chillesford Beds this change had proceeded so far that the majority of the shells it contains are of Arctic species. The refrigeration continuing, the climate at length became very cold—so cold, in fact, that the summer's heat was not sufficient to melt the accumulated snows of winter; and much of Great Britain and Ireland, together with large continental areas in northern latitudes, were covered with extensive glaciers, and at one time, with a thick sheet of ice or *ice-cap;* the climate and other conditions being much the same as those to which Greenland is subject at the present time. This "Glacial Epoch" has left innumerable traces behind, which we shall examine in detail.

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[1] Before reading this article the student should carefully read again articles 65 to 70.

The Boulder Clay.—A great portion of Scotland, and also considerable portions of the north and east of England, are covered with a mass of unstratified clay containing angular blocks of stone of all sizes. Many of these blocks or boulders have one or more plane surfaces, as if they had been rubbed along without rolling, and these faces are also frequently grooved and striated like the moraine stones of a modern glacier.

The Rocks under the Boulder Clay are generally smooth, with wavy outlines, like *roches moutonnées*, while they are scratched and furrowed like the beds of glaciers. The boulders can usually be shown to have been derived from rocks at no great distance, and the clay itself is generally tinged with the prevailing tint of the formation on which it lies. We have here abundant evidence of moving ice, the Boulder Clay, or "Till," as it is called in Scotland, being the moraine matter resulting from the abrasion of the rocks over which the ice moved.

Rounded Form of Mountains and Hills.—The general outline of the mountains of the Highlands of Scotland is remarkably rounded, and so are many of the mountains and hills of Wales and the north and east of England. These round-topped mountains, where the rocks are hard and durable, often exhibit striations and furrows, just like those of the valleys, showing that at one period not only were the valleys filled with ice, but the mountain-tops themselves were covered by it—that is to say, the whole country referred to was covered by a continuous sheet of ice, or ice-cap, so thick as to be able, by its weight and motion combined, to carve out deep valleys, and to grind off the rugged peaks of lofty mountains.

From what has been said, we infer that the Boulder Clay, or Till, unlike ordinary moraine matter, was accumulated underneath the great ice covering, forming *moraines profondes.* Hence the great extent of this clay, and its even distribution over large plains.

Similar indications of glaciation or ice sculpture exist in Ireland, in the northern portion of Europe generally, and in North America. We have thus evidence of the cold climate being very general in the northern hemisphere. In the southern hemisphere similar appearances are found, but the glaciation there may not be of the same age.

Submersion of the Land—The Glacial Drift.—The Boulder Clay in Scotland and in England is in many places covered by sands and gravels rudely stratified, and frequently containing marine shells. These beds are found at considerable elevations above the sea. They have been observed at an elevation of 2000 feet upon the sides of the mountains of Wales, and sea-shells have been obtained from them at a height of 1400 feet. We have thus evidence of the land having been submerged below the sea after the accumulation of the Boulder Clay.

The "Glacial Drift," as this marine formation is called, contains many grooved and striated stones, and the whole formation appears to be the moraine matter of the glaciers which covered the islands formed by the high parts of Scotland, Cumberland, and Wales; this moraine matter having been rudely stratified by the movements of the sea, while at the same time it was mingled with sand and sea-shells. Some of the boulders are of considerable size, and lie scattered about in numerous places where the "drift" is absent. This suggests the agency of icebergs to carry and distribute the boulders and gravel. The icebergs may have been principally derived from the glaciers of Cumberland, Wales, and Scotland, while many from the north would doubtless reach the seas contiguous to these islands, and there deposit their rocky loads. Many of the boulders or "erratic blocks" scattered about the British islands are strangers, and appear for the most part to have been derived from the Scandinavian mountains.

The southern part of England exhibits little or no trace of glaciation, and has no drift; hence it is inferred that this district was not depressed during any part of the glacial epoch.

Emergence of the Land.—The partial depression of the British area was after a long time followed by a slow movement of elevation, which has continued more or less until within recent times. The evidence is of various kinds. On the east and south coasts of England, and other parts of Great Britain, old sea-beaches occur, one below another, at considerable heights above the present sea-level; this indicates a gradual elevation. In Wales we have evidence of the upheaval in the fact that the drift is absent from many low-lying valleys which it must have once filled, having evidently been ploughed out by the glaciers, which increased in size as the elevation of the land proceeded.

Decline of the Glaciers.—After the land had fairly emerged from the sea, the climate seems to have gradually become milder, and glaciers occupying the valleys of Wales, Cumberland, the Alps, and other places, gradually declined in size. Abundant proofs of the former extension of Alpine glaciers exist, and we have similar evidence of the existence of glaciers in Wales, Cumberland, and other parts of Great Britain, in comparatively recent times. The *roches moutonnées*, with striations and groovings, show glaciers to have existed in the valleys at some period; while perched blocks and actual moraines, at various heights up the valleys, show that glaciers existed since the emergence of the land, and gradually declined in size until they disappeared.

175. Fossils of the Drift.—Most of the shells are similar to those now living in the Arctic seas. The conchifers *Astarte borealis*, *Leda oblonga*, *Cyprina Islandica*, *Cardium edule* (common cockle), and the gasteropods *Scalaria Greenlandica*, and *Dentalium entalis* are characteristic species.

Remains of plants occasionally occur, and also bones of mammals such as the elephant, rhinoceros, and reindeer. The occurrence of these indicate that at times the climate was sufficiently mild for them to migrate northwards.

176. Deposits newer than the Drift.—In many of our river valleys there occur terraces at various heights above the present level of the river. The origin of these terraces has already been explained (76, 81). The gravels forming the terraces were deposited by the river when it flowed at higher levels. In these "high level gravels" are found the bones of animals now inhabiting this country, with others inhabiting other parts of the world, and some altogether extinct. Among the mammalia are the fox, wolf, hyæna, lion, reindeer, ox, bison, hippopotamus, pig, horse, two species of elephant, rabbit, and squirrel.

It is in these deposits and others of similar age that we first meet with traces of man or his works. In river gravels, and also in several bone caves in this country, flint knives, hatchets, arrow-heads, and other works of man, are found with the bones of extinct animals such as the mammoth and cave bear. In Continental gravels and caves, not only the works of man, but his bones have been found side by side with those of the mammoth and other animals now extinct.

It is evident from the presence of the remains of these large mammalia in strata newer than the Drift, that Great Britain must have been united to the Continent since that period; the plains over which these animals migrated to England, and also to Ireland, having subsequently been destroyed by marine denudation similar to that which is now more widely separating Great Britain from the Continent, and contracting its size.

177. Recent Deposits are such as are accumulating at the present time, as, for example, vegetable soil, peat, river gravels, deltas, sea-shore deposits, and coral reefs. These have already received attention in the earlier chapters, for before proceeding to the study of geological history, it was necessary that the operations of nature concerned in producing deposits going on under our direct observation should be first understood, seeing that it is from the study of these that we derive our chief means of investigating the rocky monuments of the past ages.

QUESTIONS.

The questions to which the dates are affixed are taken from the Examination Papers of the Science and Art Department. The others are from various sources.

1. Define the chief scientific objects of Geology. (1872.)
2. What is the form of the Earth? State its specific gravity as a whole, and the average specific gravity of the known rocks at or near the surface. (1869.)
3. What is the difference between a rock and a mineral? (1865.)
4. Explain what is meant by the "Crust of the Earth?" (1869.)
5. What is meant by the term stratified rocks? (1869.)
6. How do angular stones get rounded into pebbles? and what is a conglomerate? (1869.)
7. What kind of rock is shale? (1870.)
8. What are the differences between slate and shale? (1865.)
9. How would you detect that a rock is *limestone?* (1861.)
10. What, in general terms, is the chemical composition of dolomite? (1872.)
11. Give the names of three of the commonest aqueous rocks? (the names of geological formations are not meant). (1872.)
12. State the principal difference between what are commonly called "bituminous" and anthracite coals. (1872.)
13. Classify the following stratified rocks according to their mineral composition:—sandstone, chalk, coal, clay, slate, oolite, dolomite, anthracite, marl, sand.
14. To what class of rocks does gneiss belong? (1872.)
15. Explain the terms *stratified* and *unstratified* as applied to rocks.
16. Into what two great classes have rocks been divided? How would you (in most cases) easily distinguish rocks of one of these classes from rocks of the other? (1861.)
17. Name any one kind of rock that has been formed by the action of heat—that is to say, that has been melted, and afterwards become hard by cooling. (1872.)
18. What kind of a rock is basalt? (1871.)
19. How do you know that greenstone is an igneous rock, and sandstone an aqueous rock?
20. Name the minerals which enter into the composition of granite. (1867.)
21. Igneous rocks are frequently found interbedded with aqueous rocks. How are such occurrences accounted for?
22. Classify the following rocks under the two heads, Igneous and Aqueous:—sandstone, clay, granite, syenite, sand, pumicestone, chalk, greenstone, shale, conglomerate, basalt, limestone.

23. From whence has the material that forms stratified rocks been derived? (1861.)
24. By what wasting process is the level of the land gradually lowered? (1869.)
25. What chemical agent is most active in promoting the disintegration of rocks, and how does it act? (1867.)
26. By what means are underground caverns and water-courses made in limestone rocks? (1872.)
27. Why is some water hard, and other water soft? (1872.)
28. What is the special effect of rainfall in promoting the disintegration of limestone rocks? (1873.)
29. Describe a glacier, and state what marks are left by glaciers when they disappear?
30. What is the cause of the motion of glaciers, and what effects do they produce on the rocks over which they pass? (1867.)
31. By what signs would you prove that glaciers once existed in a country where they are no longer found? (1873.)
32. What are the geological effects now produced by icebergs? (1864.)
33. Grains of sand when seen under the microscope appear smooth and not unlike miniature pebbles. How do you account for the smoothness of the grains?
34. Explain the part played by waterfalls in the erosion of ravines.
35. Compare the action of water as a disintegrating agent in its solid and liquid states.
36. Explain the geological meaning of the term *denudation.* (1865.)
37. How do you account for the irregular form of ground—that is, the continued variety of hills, valleys, etc.?
38. By what means have valleys been *scooped out* in solid rocks? (1873.)
39. Draw a section, real or imaginary, showing what is meant by an outlier. (1862.)
40. Explain by means of a diagram the effects of denudation in a country in which the rocks are contorted. (1867.)
41. Describe the action of the sea on coasts.
42. What are the general effects of marine denudation on the form of land?
43. In what different ways do rivers transport to the sea the waste matter arising from the erosion of rocks?
44. How does it happen that rivers contain various matters in chemical solution? and name some of the substances so found. (1865.)
45. Explain the manner of the formation of river deltas. (1867.)
46. Explain the action and effect of rivers in promoting the degradation of a country, and in forming sedimentary deposits.

47. Rain falls on the land and finds its way to the sea. What geological effects does it produce on its road?
48. By what means has the material in stratified rocks been arranged. (1861.)
49. Describe the action of carbonic acid on limestone rocks. In what form is carbonate of lime carried by rivers to the sea? What becomes of the carbonate of lime which reaches the sea?
50. Of what kind of microscopic organic bodies is chalk, to a great extent, composed? (1870.)
51. How do you know that chalk was formed at the bottom of the sea? (1872.)
52. By what process have thick strata of limestone, pure or nearly pure, been formed on old sea-bottoms, and are formed at the present day? (1872.)
53. Explain the mode of formation of stalactites and stalagmites.
54. Of what materials has coal been formed? (1861.)
55. Coal has been formed by the growth and decay of plants. Explain the process by which beds of vegetable matter became converted into the stony substance called coal. (1870.)
56. What evidence is there that coal was once vegetable matter?
57. Give an example of an aqueous rock the material of which has been derived from previously existing rocks, and an example of one formed mainly of the hard parts of animals.
58. Strata formed in the sea were originally soft and incoherent: by what means have they become consolidated? (1867.)
59. Trace backwards, as far as you can, the history of a consolidated stratum of sandstone or conglomerate now forming dry land.
60. What common proofs have been given to prove that the earth is heated in the interior (central heat)? (1867.)
61. What are the reasons that have induced many geologists to suppose that the outer part of the earth is a *crust* enclosing fluid matter? (1870).
62. Explain the meaning of the term *Crust of the Earth?* (1871.)
63. Describe a volcano, and mention some of the products thrown out by volcanoes.
64. What is the cause of the cone-like form of most volcanoes? (1869.)
65. What is meant by an extinct volcano? (1870.)
66. If stratified rocks were originally deposited in horizontal layers under water, how do you account for such rocks frequently forming high hills at the present time, and even lofty mountains? (1872.)
67. What conditions appear to be requisite for the existence of

reef-building corals? What are fringing reefs, barrier reefs, and atolls? How are the last explained?

68. In what way do the existence of atolls and barrier reefs prove the depression of land?
69. What do you consider to be the origin of mountain chains?
70. What is meant by metamorphism? How is it brought about? What changes does it produce on rocks? Give examples.
71. Give a definition of the term "cleavage" as applied to rocks, and explain its origin. (1868.)
72. What is a lode? (1861.)
73. By what processes do you suppose veins of quartz, calc-spar, ores of metals, etc., have been formed in lodes? (1871.)
74. What is meant to be expressed by the colours on a geological map? (1870.)
75. Explain by drawing or writing the terms dip and strike, and contorted strata. (1867.)
76. Explain the words *dyke*, *lode*, *joint*, and *cleavage*, as applied to rocks. (1862.)
77. What is a fault? (1861.)
78. Explain the meaning of the terms dip, strike, fault, lode, and stratification. (1864.)
79. Draw a section, either true or imaginary, showing contorted and horizontal strata with an outlier and a fault. (1865.)
80. Explain by writing or drawing the term unconformable stratification. (1867.)
81. Explain how unconformable stratification has been produced. (1862.)
82. What is meant by a geological section? Draw sections illustrating inclined strata, unconformable strata, a fault, anticlinal and synclinal curves.
83. What is meant by the word fossil? (1871.)
84. How have fossil shells become enclosed in rocks? (1869.)
85. What are fossils? Give some illustration of their use in geological investigation. (1867.)
86. What are the characteristics of fresh-water strata?
87. Name one or two *genera* of fossil shells by which you could prove that some strata were deposited in *fresh water*. (1871.)
88. Why are land plants and other terrestrial productions as a general rule found more frequently in arenaceous and argillaceous than in calcareous rocks?
89. What is meant by the terms univalve shell, bivalve shell, crustacea, and vertebrata? (1869.)
90. Explain by drawings the chief differences in external form between the Brachiopoda and Conchifera. (1866.)
91. Define the following terms used in geology:—*igneous*, *bed*, *outcrop*, *lode*, *fossil*, *dip*, *basin*.

92. Define the following terms:—*dyke, crater, anticlinal, silt, trap, tufa, lava.*
93. Define the following:—*strike, cleavage, stratified, outlier, schist, vesicular, moraine, escarpment.*
94. Define the following:—*denudation, stalactite, unconformable, slate, vein, section, clinometer, porphyry.*
95. What proofs are there that rocks are of different ages? (1867.)
96. How would you prove stratified rocks to be of different ages *without reference to the fossils they contain?* (1870.)
97. How would you infer geological periods to have been of long duration? (1867.)
98. When of two formations one lies unconformably on the other, what inferences do you draw from this with regard to the *lapse of time?* (1864.)
99. What is the connection between unconformability in stratification and the succession of life in time?
100. What is meant by a geological "formation?" (1872.)
101. What is the meaning of the words Palæozoic, Mesozoic, and Cainozoic, as applied to formations and fossils? (1866.)
102. Rocks are divided into Palæozoic (or Primary), Mesozoic (or Secondary), Cainozoic (or Tertiary) formations. To which divisions do the Old Red Sandstone and the New Red Sandstone belong? (1870).
103. Construct a column showing the succession of the British *Palæozoic formations*, placing the oldest at the bottom and the latest at the top. (1871.)
104. Name the chief formations included in the Mesozoic or Secondary series. (1869.)
105. Name the oldest known formation, its lithological character, and the fossil it contains. (1869.)
106. What was the nature and mode of growth of the fossil Eozoon Canadense of the Laurentian Rocks?
107. To what class of animals does a trilobite belong? (1869.)
108. Explain the leading features in the structure of a trilobite. (1866).
109. What are the oldest fossiliferous rocks in Great Britain and Ireland? Name some one fossil they contain.
110. Name a few characteristics of Silurian strata by which you recognise them to be marine deposits.
111. Name the formations in which graptolites are found. (1870.)
112. In two formations belonging to the same series (Silurian, for example), what connection is there between unconformability and more or less complete change of species? (1864.)
113. In what formation are fossil fish first found? (1872).
114. What are the principal *crustaceans* and *chambered shells* found in British strata older than the Devonian?

115. Name several genera of fishes found in the Old Red Sandstone. (1865.)
116. The Old Red Sandstone and the Devonian Rocks are usually considered to be of the same geological age. Is there any broad general distinction between their fossils? If so, what is it? (1870.)
117. Construct a column of the Carboniferous formations, placing the oldest at the bottom. (1867.)
118. Are the coal-producing strata of the British Isles older or younger than the Old Red Sandstone? (1872.)
119. How does it happen that the coal-fields of the British Coal measures often lie in the form of basins?
120. Explain why the coal-fields of Ireland are so small compared with those of Britain. (1864.)
121. In what British formations do lead ores chiefly occur? (1865.)
122. Name any fossils you remember found in the *Carboniferous Limestone.* (1871.)
123. State some leading marine fossils by which you could distinguish the Silurian from the Carboniferous formations of Britain. (1866.)
124. Shells of the genus Nautilus occur in the Carboniferous Limestone: are there any shells of that kind living now? (1870.)
125. Name the *formations* in which trilobites have been found, and specify those in which they are *most numerous.* (1873.)
126. In what formations do the genera Productus and Spirifera chiefly occur? (1870.)
127. What kind of plants are common in the Coal Measures? Name some of the genera. (1867.)
128. What relation does the fossil commonly called *Stigmaria* bear to *Sigillaria?* (1865.)
129. Can you name any *one formation* in which there are great numbers of fossil plants? (1870.)
130. State the manner in which coal occurs in the Coal Measures. (1868.)
131. What theory has been inferred from the occurrence of *underclay* beneath most beds of coal of the Coal Measures? (1871.)
132. How would you prove that beds of coal generally lie on the surface on which the plants grew, from which the coal was formed? (1866.)
133. Explain the nature of the plants of the Coal Measures, and how they were buried and turned into coal.
134. Under what peculiar circumstances was the *Magnesian Limestone* of the Permian strata deposited? (1873.)
135. State the divisions of the New Red or Triassic series, and the position of rock-salt in that series, and its origin.

136. State one or more broad leading distinctions in the grouping of the fossils of the Palæozoic and Mesozoic (Secondary) rocks. (1867.)

137. Give examples of *Palæozoic genera* that became *extinct* before the commencement of the *Secondary* period. (1872.)

138. How would you readily distinguish Palæozoic and *Secondary marine formations* from each other by means of *bivalve shells?* (1866.)

139. State one great distinction between Palæozoic fishes and those of later date. (1865.)

140. In what British formation does the oldest known mammal occur, and what is its name? (1870.)

141. What proofs are there of a long continental European epoch between the close of the Silurian period and the beginning of the Rhaetic Beds?

142. Where does the Oolitic series occur in England? what are the principal formations which compose it?

143. How would you prove that the *Oolitic Coal* of Yorkshire is of *different age* from the *coal of the Coal Measures?* (1862.)

144. Name some genera of fossils common in the Lias and Oolite. (1868.)

145. What kind of fossil shell is an ammonite? (1870.)

146. State the general lithological characters of the British Liassic and Oolitic strata. Name some of the genera of fossil shells very common in these formations.

147. Whether are the Purbeck and Wealden beds chiefly composed of strata formed *in the sea*, or of strata formed in *fresh water?* (1870.)

148. What are the reasons for the belief that the Purbeck and Wealden strata were chiefly deposited in fresh water at the mouth of a river? (1867.)

149. Are there any species of shells in common between the Oolitic rocks and the Chalk? (1868.)

150. To what order in the animal kingdom do Belemnites belong? In what formation are they most abundant? (1872.)

151. Is there any Chalk on the Continent of Europe of later date than the British Chalk? If so, where does it lie, and what kinds of fossils does it contain different from those in Britain? (1870.)

152. How do you know that the Chalk was deposited at the bottom of a sea? (1872.)

153. Under what conditions do you suppose the *Chalk* to have been formed? (1871.)

154. How may the occurrence of flints in Chalk be explained? In what part of the Cretaceous series in Britain are flints found?

155. Name those formations in which the remains of reptiles are most numerous. Name some of the reptiles. (1867.)
156. In what formations are ammonites most common? (1871.)
157. Name several genera of Brachiopoda common in the Secondary rocks. (1866.)
158. Name some genera of *Cephalopoda* found only in the Palæozoic rocks, and some found only in the Secondary rocks. (1869.)
159. Name the principal formations of the English *Eocene rocks* (Lower Tertiary), and state *the conditions* under which they were formed. (1871.)
160. Name any of the *genera or species* of fossils found in the oldest Tertiary or Eocene rocks. (1861.)
161. Construct a column of the *British Eocene formations*, and distinguish the *marine* strata by a cross. (1873.)
162. In what geological period do the remains of large land animals (mammalian quadrupeds) first appear in abundance? (1872.)
163. Name some geological formations in which fossil ferns are common. (1868.)
164. What is the nature of the European fossil flora of Miocene age? (1870.)
165. In what part of Britain are *Miocene* strata known, and what fossils do they contain that lead you to infer they are of Miocene age. (1869.)
166. What kinds of *fossils* have been found in the rocks of the *Sewalik Hills* of India, and what is the geological age of these rocks? (1871.)
167. What is meant by the terms Eocene, Miocene, and Pliocene? What deposits in the British Isles are generally referred to the second and third of these?
168. Do you know any formations that show evidence of cold climates? if so, name them. (1867.)
169. What are the proofs of a very cold climate in the Northern Hemisphere in Post-Pliocene times?
170. Name some of the mammalia that lived in the Northern Hemisphere during the Glacial Period. (1865.)
171. How would you prove that Britain has been united to the Continent shortly before and immediately after the Glacial Period? (1870.)
172. Name four genera of Mollusca that have become extinct since Secondary times, and four that have lived from Secondary times to the present day. (1865.)
173. In what British formations have the remains of mammalia been found? (1867.)
174. Name those formations in the Palæozoic, Secondary, and Tertiary strata of the British Islands, in which marine fossils are numerous. (1866.)

175. Name the chief genera of univalve and bivalve shells found fossil in British fresh-water formations. (1864.)
176. Name the fresh-water strata or formations in the British series of rocks. (1862.)
177. Name all the British formations the whole or part of which have been formed not in the open sea, but at river mouths, and in inland lakes salt and fresh.
178. Mention a living animal and a fossil belonging to each of the following classes:—Pisces, Crustacea, Echinodermata, Cephalopoda, Lamellibranchiata, Brachiopoda, and Actinozoa.
179. Draw a section across any part of the country with which you are best acquainted, and describe it. (1872.)

EXERCISES.

I. From a collection of rocks and minerals select the following:—quartz, basalt, haematite, felspar, augite, calc-spar, anthracite, and write a short description of each.

II. Select:—sandstone, mica, oolite, gypsum, fluor spar, lignite, dolomite, gneiss, and describe as before.

III. Select and describe:—conglomerate, shale, hornblende, quartzite, granite, clay slate, crystalline limestone, obsidian, and diorite.

IV. Draw diagrams, Figs. 9 and 10, to twice the scale, and explain them in your own words.

V. Draw diagrams, Figs. 23, 25, and 26, to twice the scale, and give an original description of each.

VI. Separate a group of shells, coral, bones, and other parts of animals, into their proper classes.

VII. Suppose a straight line to pass from Lowestoft to Aberystwith, over what formations does it pass?

VIII. Across what formations does the 54th parallel of N. latitude pass in England and Ireland?

IX. What formations are passed over in going from London to Brighton?

X. Trace the 52nd parallel of N. latitude in England or Ireland, and state over what formations it passes.

XI. Draw one of the sections, Figs. 50, 51, to twice the scale.

XII. Make out a table, in which arrange all the fossils mentioned in this book, according to the classes of animals or plants to which they belong.

XIII. On a large sheet of paper, make out a table of British strata, placing all the formations in one column (the oldest at the bottom); lithological characters, unconformities, etc., in a second column; and the characteristic fossils in a third column.

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